2012-09

Network Vulnerability Assessment of the U.S. Crude Pipeline Infrastructure

Larranaga, Michael D.

Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/17396

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

NETWORK VULNERABILITY ASSESSMENT OF THE U.S. CRUDE PIPELINE INFRASTRUCTURE

by

Michael D. Larrañaga

September 2012

Thesis Co-Advisors: Rudy Darken
Ted Lewis

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2012	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Network Vulnerability Assessment of the U.S. Crude Pipeline Infrastructure			**5. FUNDING NUMBERS**
6. AUTHOR(S) Michael D. Larrañaga			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number _______N/A________.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

The potential for cascade failure of the U.S. crude oil pipeline infrastructure is analyzed using Model Based Risk Assessment software. The pipeline system that distributes crude oil to refineries across the United States has gained much media attention with President Obama's denial of a permit to complete a key portion the Keystone-XL pipeline that will carry oil from Alberta, Canada to the Cushing Oil Trading Hub (COTH) in Cushing, OK. The analysis identified the COTH as the primary critical hub. The COTH is one of the world's major oil terminals. A disruption of the COTH, Midwest/West Coast oil distribution networks, or critical hubs would have far-reaching negative consequences affecting global trade. The analysis also identified regional differences in network resiliency and susceptibility to cascade failure. Protecting all 55,000 miles of the U.S. crude oil pipeline infrastructure from catastrophic failure is an unachievable goal, but protection of the network from cascade failure and a Black Swan event can be achieved by protecting network hubs. The results of this analysis should be used as a starting point to increase network resiliency and prioritize the use of resources to secure the crude oil pipeline network against cascade failure.

14. SUBJECT TERMS Critical Infrastructure, Crude Oil Pipeline, Probable Maximum Loss, Model Based Risk Analysis, Risk Assessment, Risk Management, Black Swan, Network Analysis, Fat Tail, Simulation, Pipeline Safety, Safety Management			**15. NUMBER OF PAGES** 85
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

NETWORK VULNERABILITY ASSESSMENT OF THE U.S. CRUDE PIPELINE INFRASTRUCTURE

Michael D. Larrañaga
Simplex Professor, School of Fire Protection and
Safety-Oklahoma State University, Stillwater, Oklahoma
Member, Board of Scientific Counselors-Centers for Disease Control and Prevention-
National Institute for Occupational Safety and Health, Washington, DC
B.S., Oklahoma State University, 1996
M.S., University of Houston Clear Lake, 1998
Ph.D., Texas Tech, 2004

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF ARTS IN SECURITY STUDIES (HOMELAND SECURITY AND DEFENSE)

from the

NAVAL POSTGRADUATE SCHOOL
September 2012

Author: Michael D. Larrañaga

Approved by: Rudy Darken
Thesis Co-Advisor

Ted Lewis
Thesis Co-Advisor

Daniel Moran
Chair, Department of National Security Affairs

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The potential for cascade failure of the U.S. crude oil pipeline infrastructure is analyzed using Model Based Risk Assessment software. The pipeline system that distributes crude oil to refineries across the United States has gained much media attention with President Obama's denial of a permit to complete a key portion the Keystone-XL pipeline that will carry oil from Alberta, Canada to the Cushing Oil Trading Hub (COTH) in Cushing, OK. The analysis identified the COTH as the primary critical hub. The COTH is one of the world's major oil terminals. A disruption of the COTH, Midwest/West Coast oil distribution networks, or critical hubs would have far-reaching negative consequences affecting global trade. The analysis also identified regional differences in network resiliency and susceptibility to cascade failure. Protecting all 55,000 miles of the U.S. crude oil pipeline infrastructure from catastrophic failure is an unachievable goal, but protection of the network from cascade failure and a Black Swan event can be achieved by protecting network hubs. The results of this analysis should be used as a starting point to increase network resiliency and prioritize the use of resources to secure the crude oil pipeline network against cascade failure.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

bpd	Barrels Per Day
CIS	Critical Infrastructure Sectors
COTH	Cushing, Oklahoma Oil Trading Hub
DHS	Department of Homeland Security
DOT	Department of Transportation
ECIS	Energy Critical Infrastructure Sector
GAO	General Accounting Office
IPT	Integrated Physical Protection
MBRA	Model-Based Risk Analysis
NPS	Naval Postgraduate School
NTSB	National Transportation Safety Board
OPS	Office of Pipeline Safety
PADD	Petroleum Administration for Defense District
PMLRisk	Probable Maximum Loss Risk
TCIS	Transportation Critical Infrastructure Sector
TSA	Transportation Safety Administration
WTI	West Texas Intermediate

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

I would like to thank my beautiful wife, Patricia and beautiful daughter, Ana Sofia for providing me with wonderful support and the time to realize my forgotten dream of graduating from a military service university. Their sacrifice is more gracious than words can describe. I would like to thank my parents, Leandro and Guadalupita, for inspiring in me a thirst for knowledge and a quest for lifelong learning and the Flores family for their kindness.

Attending the Naval Postgraduate School (NPS) has been an honor. I thank my thesis advisors, Ted Lewis and Rudy Darken, and the amazing faculty and staff of the Center for Homeland Defense and Security, who “changed my way of thinking” and helped me complete a thesis on a topic of great national importance. I would like to thank my supervisor at Oklahoma State University, Dr. Jim Bose, for allowing me the time flexibility to complete the NPS program.

I have been blessed with amazing mentors who have contributed greatly to my success. Thank you Bill Holder, Rixio Medina, George Dixon, Dale Janes, Dee and Adair Margo, Enusha Karunasena, and Steve McKeever. And to my research advisors for previous educational endeavors; thank you Dennis Casserly, Mario Beruvides, and David Straus. I would also like to thank my graduate students, Patrick Smith and John Bennett, without whom I could not have completed this project. I would like to graciously recognize Tim Manning of the Federal Emergency Management Agency for his support and dedication to the nation. The Department of Homeland Security deserves special recognition for funding initiatives dedicated to educating current and future homeland security leaders.

I would like to recognize the members of Team America and my fellow classmates, who serve to protect and defend our great nation and its citizenry. I am indebted to your service, loyalty, and commitment. Finally, I would like to thank Dr.’s Perry Logan, of 3M and John Howard, of the Centers for Disease Control and Prevention-National Institute for Occupational Safety and Health for believing in me.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

The United States has an overwhelming dependency on crude oil and is the largest consumer of crude oil in the world. It leads the world in oil consumption, and consumes approximately 19 million barrels of crude oil per day, or two-thirds more than that of the European Union and double the consumption of China, which are second and third in world oil consumption, respectively.[1] For the United States to move such a large volume of oil across the country, a massive pipeline network was developed that began in the 19th century. The purpose of this project was to assess the nation's crude oil pipeline network and identify the hubs that would have the greatest impact if their operation were disrupted by a terrorist attack, natural disaster, or other catastrophic event.

Crude oil pipeline infrastructure is critical to the North American energy supply chain that has evolved substantially over the past century. The U.S. economy relies almost completely on crude oil pipelines as critical infrastructure for enabling business, transportation, heating and energy production, petrochemical production, raw materials for manufacturing, lubrication products, and hundreds of other uses critical to the American way of life. Without the daily delivery of crude oil to U.S. refineries via the vast and complex network of crude oil pipelines, the U.S. economy would rapidly decline and become unsustainable.

Prior to the passage of pipeline safety legislation in 2002, pipeline safety and security were not considered a priority by government regulators.[2] In 1968,[3] Congress created the main regulatory body, the Office of Pipeline Safety (OPS) within the Department of Transportation (DOT) to conduct a "national program to ensure the safe, reliable and environmentally sound operation of the Nation's pipeline transportation

[1] "CIA–The World Factbook," (n.d.), https://www.cia.gov/library/publications/the-world-factbook/rankorder/2174rank.html.

[2] Carol Parker, "The Pipeline Industry Meets Grief Unimaginable: Congress Reacts with the Pipeline Safety Improvement Act of 2002," *Natural Resources Journal* 44, no. 1 (2004): 244–282.

[3] Ibid.

system."[4] In 1978, the General Accounting Office (GAO) reported that OPS had weak enforcement, maintained inaccurate records, and administered ineffective rules. In 2000, the GAO again reemphasized its 1978 findings that criticized the OPS for its unwillingness to work with states to improve pipeline safety and its weak enforcement of safety rules.[5] As of 2001, OPS did not maintain an accurate map of the pipelines it regulated. Additionally, OPS had the lowest implementation rate of National Transportation Safety Board (NTSB) recommendations of any agency in DOT. The NTSB, DOT Inspector General, American Petroleum Institute and both houses of Congress were critical of OPS's poor history of accident data collection, regulation, and enforcement of existing regulations.[6]

In a review of 319 pipeline safety related journal articles from 1971–2000 that identified trends by frequency of keyword content analysis methodology, Larrañaga and Sandoval found an exponential growth rate in keyword frequency or pipeline safety related terms per time period in the published literature. The number of journal articles published from 1971–2000 grew exponentially per time period, which indicated an increasing awareness of pipeline safety issues in the scientific community. See Figure 1. During these same time periods, the frequency of use of the term "legislative/regulation" increased 237%, the keyword "accidents" increased 244%, and the term "safety management" increased 408%.[7] Despite the increased awareness of safety related issues in the scholarly literature, it took several catalyzing incidents from 1999–2001 to generate the impetus for new pipeline safety legislation.

---

[4] DOT-PHMSA, "PHMSA—Organization—Office of Pipeline Safety," (n.d.), http://www.phmsa.dot.gov/portal/site/PHMSA/menuitem.ebdc7a8a7e39f2e55cf2031050248a0c/?vgnextoid=ca9fe4fca0380110VgnVCM100000762c7798RCRD&vgnextchannel=8938143389d8c010VgnVCM1000008049a8c0RCRD&vgnextfmt=print.

[5] Parker, "The Pipeline Industry Meets Grief Unimaginable: Congress Reacts with the Pipeline Safety Improvement Act of 2002."

[6] Ibid.

[7] Michael D. Larrañaga, and Angela Sandoval, "Current Safety Issues Associated with Natural Gas Transportation and Distribution," presented at the X Congreso y Exposición Iberoamericana de Tecnologías en Prevención de Incendio, Protección Ambiental y Seguridad Industrial SEGUR-Fire 2001, Caracas, Venezuela, July 2001.

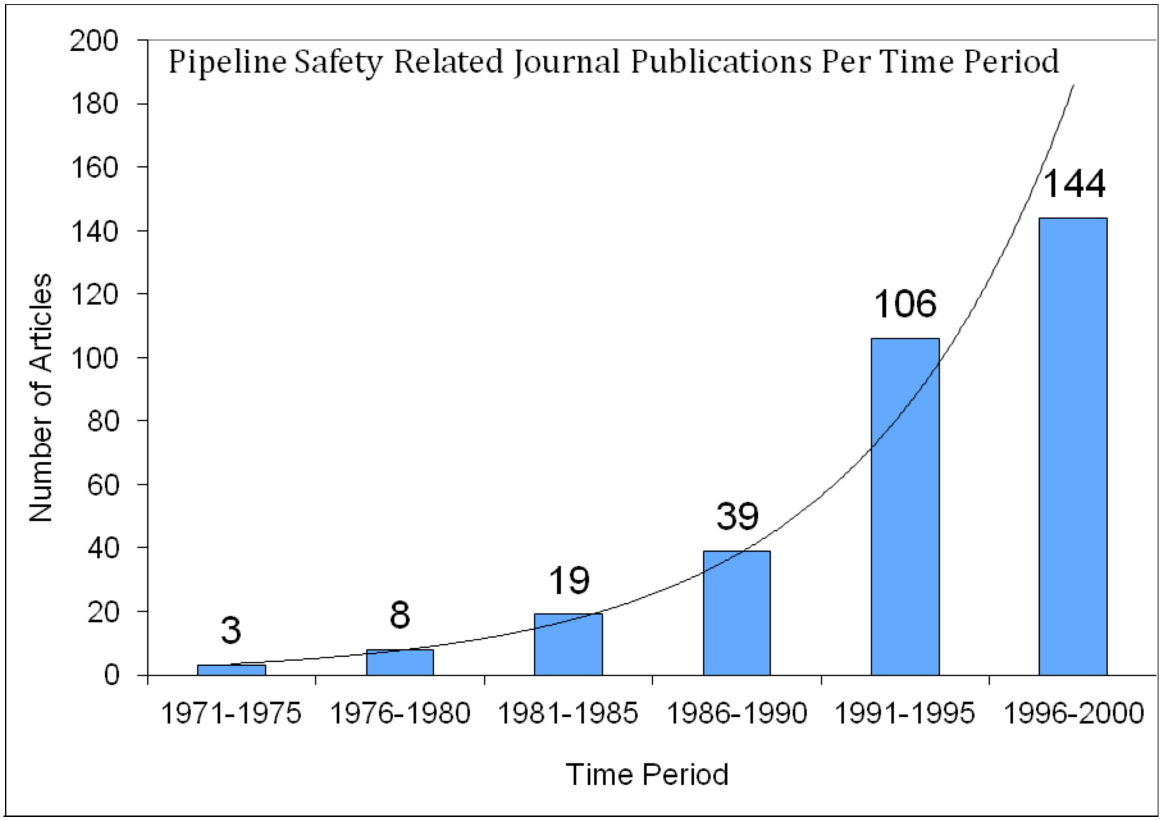


Figure 1. Pipeline Safety Related Journal Publications per Time Period

These major incidents led to President Bush to sign the new Pipeline Safety Improvement Act of 2002, which capped years of effort to strengthen pipeline safety laws by the NTSB, state agencies, and others, including victims of pipeline accidents that included the following.[8]

- 1999, Bellingham, Washington—approximately 250,000 gallons of gasoline spilled from a ruptured pipeline/explosion. Three children were killed and a fireball 1.5 miles long was sent through a city of approximately 70,000 people. The explosion created a mushroom cloud 6 miles high and damage claims exceeded half a billion dollars.
- 2000 Carlsbad, New Mexico—An El Paso Energy natural gas pipeline explosion killed 12 campers from a single family. This incident contributed significantly to the California energy crisis of 2001. The governor of New Mexico referred to the scene as “grief unimaginable.”

[8] Parker, “The Pipeline Industry Meets Grief Unimaginable: Congress Reacts with the Pipeline Safety Improvement Act of 2002.”

- 2000 Dallas, Texas—The rupture of a gasoline pipeline resulted in a contaminated water supply, which led to $2.75/gallon gasoline and lower air quality in Chicago and Milwaukee.
- 2000, Michigan—A gasoline pipeline rupture caused more than 1,200 people to evacuate their residences, and some for more than 3 months.
- 2000, Maryland—A fuel oil pipeline rupture contaminated miles of the Patuxent River, which resulted in clean up costs of $71 million.

An additional 227 pipeline failures occurred in the year 2000 that caused a record $197 million in property damage and the highest number of fatalities in 25 years. Two catastrophic events associated with security and pipelines were the venerable "straw that broke the camels back" and catalyzed change in pipeline safety legislation. The first was the September 11, 2001 terrorist attacks, and the second, just one month later, was a lone gunman who fired a rifle at the Trans-Alaska pipeline and created a leak that shut down one-fifth of domestic oil production.[9] Both these security incidents highlighted the vulnerability of pipelines to security breaches. Although the pipeline safety and security bill was introduced in the House as the "Pipeline Infrastructure Protection to Enhance Security and Safety Act," political considerations removed all sections expressly addressing security, which resulted in the final bill being the "Pipeline Safety Improvement Act of 2002."[10]

Following the September 11, 2001 terrorist attacks, the Department of Homeland Security (DHS) was created by integrating 22 existing departments within the federal government. One of these departments, the Transportation Safety Administration (TSA), was given the responsibility of overseeing the country's pipeline security. TSA has built on OPS's previous security recommendations to operators, and both agencies are now working together to ensure the nation's pipelines are both safe and secure.[11]

---

[9] Parker, "The Pipeline Industry Meets Grief Unimaginable: Congress Reacts with the Pipeline Safety Improvement Act of 2002."

[10] Ibid.

[11] U.S. Library of Congress, Congressional Research Service, *America's Pipelines Safe and Secure: Key Issues for Congress*, by Paul W. Parfomak, CRS Report R41536 (Washington, DC: Office of Congressional Information and Publishing, March 13, 2012).

With these improvements to pipeline security over the last decade, the U.S. pipeline network should be more secure than ever. With the increased recognition of the pipeline network as a critical infrastructure, it is important to utilize protection resources wisely and in the most effective manner possible. This analysis seeks to provide insight on where resources can be most useful to optimize protection.

THIS PAGE INTENTIONALLY LEFT BLANK

II. BACKGROUND

With the 1860 oil boom in Pennsylvania fueling the world's appetite for oil, a need developed for an efficient way to transport large volumes of oil to refineries. Early transportation methods relied on horse drawn carts to move oil filled whiskey barrels from the production fields to river barges and trains that then took the oil to refineries.[12] This method quickly became impractical, and in 1865, a man named Van Syckel replaced the whiskey barrels with the world's first oil pipeline. Syckel's pipeline was six inches in diameter, constructed of wood, and relied on gravity to move its 80 barrel per hour capacity five miles.[13] His idea spread, and small pipelines, known as gathering lines, quickly became the main means of transporting crude over short distances. While this reduced the time needed to move the crude oil to refineries, transportation over long distances was still reliant on trains.[14]

In 1878, the first large pipeline, or trunk line, was built by the Tidewater Oil Company. This pipeline was constructed in secret to avoid interference by the powerful Standard Oil Company. The six-inch iron pipe stretched 109 miles over mountainous terrain and required an 80 horsepower pump to push the crude at a rate of 250 barrels per hour.[15] Soon, the number of trunk lines connecting oil fields to refineries grew, which made crude oil transportation even more efficient.

The crude oil pipeline infrastructure continued to grow over the next several decades with the use of larger pipes and improved technology. With the U.S. involvement in World War II, a need was recognized to distribute oil across the nation more effectively. As a result, the War Department established the Petroleum Administration for

---

[12] BP, "BP Pipelines—Our History," (n.d.), http://www.bppipelines.com/history.html.

[13] BP, "BP Pipelines—Our History"; Phil Hopkins, "Oil and Gas Pipelines: Yesterday and Today," 2007, www.penspen.com/Downloads/Papers/.../OilandGasPipelines.pdf.

[14] Samuel T. Pees, "Oil History," 2004, http://www.petroleumhistory.org/OilHistory/pages/Pipelines/BigYear.html.

[15] Ida Minerva, *The History of the Standard Oil Company: 2 Volumes in 1* (The MacMillan Company, 1904); Floyd L. Hartman, "1879: Tidewater Pipe Company—World's 1st Successful Oil Pipeline," 2009, www.smethporthistory.org/coryville/tidewatermap.html.

Defense. This administration created five Petroleum Administration for Defense Districts (PADDs) across the United States. Each PADD oversaw the refining and distribution of oil within its own district as shown in Figure 2.[16] Although the PADDs were created during WWII when gasoline was rationed, they are used today for supply monitoring.[17] After Nazi submarines became more active in the Atlantic Ocean and sunk several merchant-marine tankers threatening the east coast's oil supply, new crude oil pipelines were constructed to make the PADDs more interconnected and less vulnerable to catastrophic interruption of service.[18] This led to an increased reliance on pipelines for the delivery of crude oil.

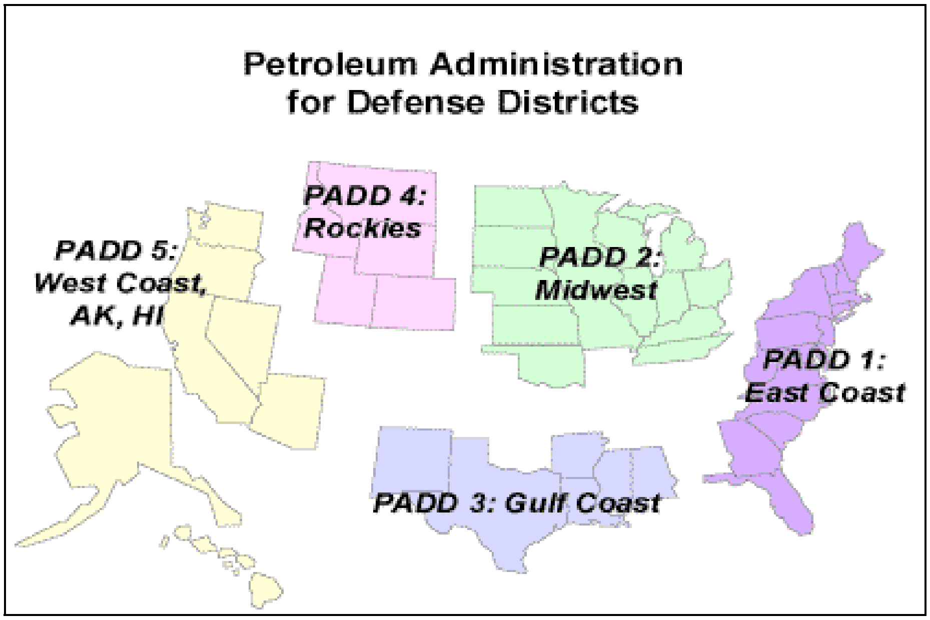


Figure 2. Petroleum Administration Defense Districts.[19]

[16] National Archives, "Records of the Petroleum Administration for Defense," 1950; Oil Infrastructure Subgroup, "Crude Oil Infrastructure," *NPC North American Resource Development Study*, September 15, 2011, http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCYQFjAA&url=http%3A%2F%2Fwww.npc.org%2FPrudent_Development-Topic_Papers%2F1-7_Crude_Oil_Infrastructure_Paper.pdf&ei=q2wxT8enGZTHsQLl7IjwBg&usg=AFQjCNEj8mFdkY0ysInCPfGzfpveDVEWzg.

[17] Theodore Lewis, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation* (Hoboken, NJ: John Wiley & Sons, 2006), 296.

[18] National Archives, "Records of the Petroleum Administration for Defense."

[19] Oil Infrastructure Subgroup, "Crude Oil Infrastructure."

Since WWII, the U.S. crude oil pipeline network has continued to grow and become even more interconnected. It now stretches over 55,000 miles and transports millions of barrels of crude oil per day.[20] This large network supports both the U.S. economy and military, which makes it one of the nation's most valuable critical infrastructure components.

A. LITERATURE REVIEW

The United States consumes approximately 19–20 million barrels per day (bpd) of petroleum products.[21] A complex web of pipeline infrastructure and water transport routes moves crude oil from where it is extracted from the earth (oil fields, oil basins, offshore oil fields, and oil seaports via importation) to where it is processed and refined for delivery to the marketplace in a variety of forms: gasoline, diesel, heating oil, aviation fuel, lubricants, and raw materials for the development of a variety of other products that this nation uses every day. These other materials include plastics, light bulbs, shoes, medical equipment, rubber, construction materials, and a variety of other products.[22]

Crude oil pipeline infrastructure is critical to the North American energy supply chain that has developed over the past century.[23] The U.S. economy relies almost completely on crude oil pipelines as critical infrastructure for enabling business, transportation, heating and energy production, petrochemical production, raw materials for manufacturing, lubrication products, and hundreds of other uses critical to the American way of life. Without crude oil being delivered on a daily basis to refineries across the United States via the vast complex network of crude pipelines, the U.S. economy would fail, and the return to the use of horse-drawn carriages as a major mode of transportation would be incontrovertible.[24] Crude oil is delivered to a complex

---

[20] Oil Infrastructure Subgroup, "Crude Oil Infrastructure."

[21] "CIA–The World Factbook"; Neal Adams, *Terrorism & Oil* (Tulsa, OK PennWell Corp., 2003), 32; Cheryl J. Trench, "How Pipelines Make the Oil Market Work—Their Networks, Operation and Regulation," December 2001, 1, http://www.pipeline101.com/Overview/crude-pl.html.

[22] Adams, *Terrorism & Oil*, 2–3.

[23] Oil Infrastructure Subgroup, "Crude Oil Infrastructure," 4.

[24] Adams, *Terrorism & Oil*, 1.

network of refineries across the United States, whereby the crude oil is processed and refined into finished products, such as gasoline, kerosene, aviation fuel, and other chemicals for delivery to market. Crude oil itself falls under the Energy Critical Infrastructure Sector (ECIS) as defined by the U.S. Department of Homeland Security (DHS), while the crude oil pipeline infrastructure falls under both the ECIS and the Transportation Critical Infrastructure Sector (TCIS).[25] Without a stable ECIS, the health and welfare is threatened and the U.S. economy cannot function.[26] Figure 3 shows the interdependencies of the 18 Critical Infrastructure Sectors (CIS) and the criticality of the ECIS to all other sectors.

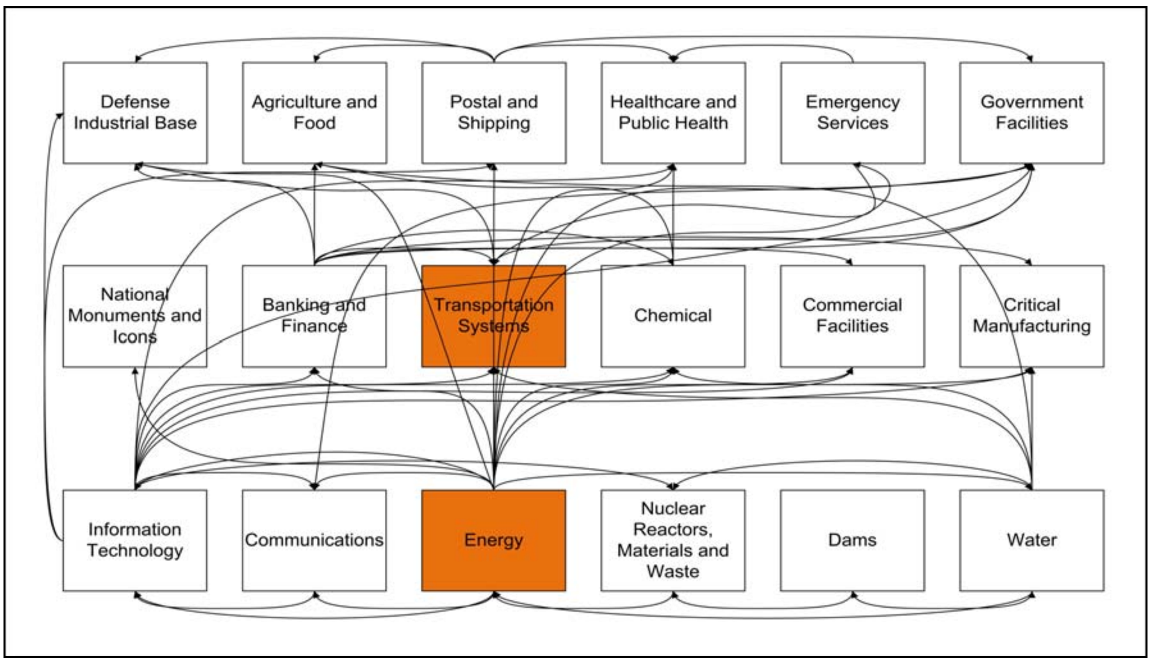


Figure 3. Dependence Diagram (Connecting Lines Indicate Sector Dependence on Each Other) of U.S. Department of Homeland Security Critical Infrastructure Sectors.[27] Adapted from Lewis, 2006.[28]

---

[25] Department of Homeland Security, "DHS Critical Infrastructure," (n.d.), http://www.dhs.gov/files/programs/gc_1189168948944.shtm.

[26] DHS, "DHS-Energy Sector: Critical Infrastructure," (n.d.), http://www.dhs.gov/files/programs/gc_1189013411585.shtm.

[27] Department of Homeland Security, "DHS Critical Infrastructure."

[28] Lewis, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation*, 57.

The price of crude oil is set based on the market clearing location for the COTH in the heart of the midcontinent region of the United States. The U.S. crude pipeline infrastructure is divided into PADDs. Most crude in PADDs II, III, and IV, and the fuel imported from Western Canada, travels through the COTH for redistribution via the vast pipeline network to refineries in PADDS II, III, and IV.[29] For most of the 20th century, Tulsa, Oklahoma was known as the "Oil Capitol of the World" and developed in to one of the most important hubs in the oil industry. A major oil gusher at Glenpool, 15 miles south of Tulsa, was discovered in 1905, which prompted a rush of entrepreneurs to the area.[30] The Glenpool basin was owned in large part by Henry Ford Sinclair and became central to the formation of the Sinclair Oil Company in 1916. In 1907, Oklahoma became the nation's largest oil producer.[31] Major oil basins at Cushing were subsequently discovered in 1912 and Cushing became a center for exploration and production of nearby oil fields. By 1914, the Cushing field was producing 50,000 barrels per day, or one-quarter of the entire state's production.[32] In 1928, the Oklahoma City Field was discovered and soon became the nation's largest oil producing basin. From 1916–1929, several major oil and oil service entities were founded in Oklahoma, including Sinclair Oil, Marland Oil (merged with Conoco in 1929), Cities Services Oil Company (now CITGO), Champlin Petroleum Co. (now Champlin Refining Company), Phillips Petroleum Co., American Association of Petroleum Geologists, Halliburton, Noble Corporation, Anderson & Kerr Drilling (Kerr-McGee, purchased by Anadarko Petroleum in 2005) and others.[33] At least two refineries operated in Cushing. As nearby oil fields began to run dry in the 1940s, production became less important and the maze of

[29] Oil Infrastructure Subgroup, "Crude Oil Infrastructure," 5.

[30] Wikipedia, the Free Encyclopedia, "Tulsa, Oklahoma," (n.d.), http://en.wikipedia.org/wiki/Tulsa,_Oklahoma.

[31] Dan Boyd, "Milestones in the Oklahoma Oil and Gas Industry," *Oklahoma Geological Survey*, (n.d.), http://www.ogs.ou.edu/oilgasmilestones.php.

[32] Ibid.

[33] Ibid.

pipelines and storage tanks that had been built to service the Cushing refineries began to transport crude to Cushing and other refining markets.[34]

The COTH first developed as an oil-trading center and then became the official price settlement point for the West Texas Intermediate (WTI) crude, the benchmark against which most types of North American Crude are priced. The COTH is now best known as a bottleneck for the energy industry.[35] For the past four decades, the COTH has supplied crude oil from Gulf Coast imports and domestic Mid-Continent areas to Midwest refining markets.[36] As such, the crude pipeline system evolved from the pre-WWII era of mostly distributing domestic supply from the Mid-Continent areas to refining markets to moving both domestic supplies and Gulf Coast imports to the interior of the country, mostly through Cushing, where crude could be redistributed to refineries across the Midwest. As supplies from domestic sources declined, the crude oil pipeline system was reversed to deliver crude oil produced in Alberta, Canada to the COTH where Canadian crude could be distributed to both Midwest and Gulf Coast refining markets.[37] More recently, other crude pipelines reversed flow direction due to increasing domestic supplies from shale reserves in North Dakota and Texas, which brings additional crude supplies through the COTH.[38]

U.S. refining capacity is highly concentrated along the Gulf Coast between Galveston, Texas and Baton, Rouge, Louisiana. Many petroleum companies have moved either corporate or operations capability to Houston, Texas because of the highly centralized oil activity along the Gulf Coast. The largest two refineries in the United States (Baytown, Texas and Baton Rouge, Louisiana) produce 5% of the national refined

---

[34] Wikipedia, the Free Encyclopedia, "Cushing, Oklahoma, (n.d.), http://en.wikipedia.org/wiki/Cushing,_Oklahoma.

[35] Matthew Phillips, "Unlocking the Crude Oil Bottleneck at Cushing," *Business Week*, May 16, 2012, http://www.businessweek.com/articles/2012-05-16/unlocking-the-crude-oil-bottleneck-at-cushing#p1.

[36] Institute for Energy Research, "The Booming Sooners: Vast Energy, Low Prices, Low Unemployment," July 11, 2012, http://www.instituteforenergyresearch.org/2012/07/11/those-booming-sooners-plentiful-energy-low-energy-prices-low-unemployment/.

[37] Ibid.; Phillips, "Unlocking the Crude Oil Bottleneck at Cushing."

[38] Institute for Energy Research, "The Booming Sooners: Vast Energy, Low Prices, Low Unemployment"; Phillips, "Unlocking the Crude Oil Bottleneck at Cushing."

products supply and the top 10 refineries produce 20% of the total. One hundred fifty-two refineries are located in 32 states, and are mostly concentrated in PADDs II, III, and IV. The vulnerability and critical nature of the refining network was highlighted in 2005 when Hurricane Katrina slammed the Gulf Coast and interrupted the nation's energy supply chain, which resulted in increased fuel prices nationwide.[39]

Five of the top 10 producing refineries are located in the Gulf Coast geographic cluster and produce 11% of the total U.S. supply.[40] Over the past decade, the United States has trended away from its reliance on waterborne imports, and moved towards imports from Western Canada via crude pipeline. Since 1987, imports of Canadian crude oil have tripled to approximately 2.5 million barrels per day with most of the increase occurring during the past decade.[41] This shift has resulted in significant changes in the Midwest and Rocky Mountain regions. Many of the pipeline networks in these regions were established to supply domestically produced light crude from Texas and the Gulf Coast region to large refining hubs in PADD II. Northbound crude flow from Cushing, Oklahoma and St. James, Louisiana were once the backbone of the crude oil pipeline infrastructure for the Mid-Continent, Gulf Coast, and Midwest regions. Today, they form redundancy as flow is reversed and Canadian crude is distributed southbound through Cushing and down to Texas and the Gulf Coast.[42]

The Rocky Mountain region faces the same situation whereby a surplus of light Rocky Mountain crude supply exists, coupled with increasing availability of Canadian crude that resulted in lower takeaway pipeline capacity for Rocky Mountain crude. The growth of alternative crude supplies in PADD II and increasing Canadian production and crude imports is causing an imbalance in the traditional crude market dynamics in the Gulf Coast region.[43]

---

[39] Lewis, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation*, 297–298.

[40] Ibid.

[41] Oil Infrastructure Subgroup, "Crude Oil Infrastructure," 7.

[42] Ibid.

[43] Ibid.

Both the East Coast (PADD I) and the West Coast (PADD V) remain largely independent markets from the remaining PADDs yet face unique challenges. California has no intra- or inter-regional pipeline infrastructure, and the California Energy Commission has forecasted the need for expansive modifications to waterborne import facilities and tankage by 2030 to accommodate the state's increasing crude demands and the replacement of existing import facilities already past their useful lives.[44] The East Coast region faces similar challenges.

Despite the changes in market dynamics, PADD II, specifically the COTH, remains the nexus of the North American crude supply, maintains the most critical crude pipeline infrastructure, and distributes the vast majority of the U.S. crude supply on a daily basis. The COTH stores 5–11% of the total national crude inventory and serves as the price settlement point for the benchmark WTI on the NYMEX.[45] The COTH distributes approximately 14 million barrels per day and services several major pipeline corridors for the receipt of oil from U.S. oil basins or foreign imports for distribution to refineries, where the oil is then processed into other products and shipped to market. The COTH receives imported Canadian crude via the Keystone pipeline (590K bpd) for distribution to refineries. The proposed Keystone-XL pipeline that runs from Canada to the COTH and on down to Port Arthur, Texas would increase the capacity of the Keystone Pipeline System (Keystone + Keystone-XL) to 1.3 million bpd and serve to increase the amount of crude imported from Canada. The Keystone-XL pipeline will connect the COTH to receive Canadian oil and continue through Oklahoma to terminals in Nederland, Texas to serve the Port Arthur, Texas refining facilities.[46] The estimated completion date for the Keystone-XL pipeline is unknown at this time due to President Obama's denial of the permit for the construction of the pipeline that will transport crude from Alberta, Canada to Steele City, Kansas and then down to the COTH.[47] The existing

---

[44] Oil Infrastructure Subgroup, "Crude Oil Infrastructure," 7.

[45] Ibid., 8; Brett Clanton, "Oklahoma Oil Hub Helps Keep Oil Prices from Going Higher," *Houston Chronicle*, March 3, 2011, http://www.chron.com/business/energy/article/Oklahoma-oil-hub-helps-keep-oil-prices-from-going-1550679.php.

[46] TransCanada, "Keystone Pipeline Project," (n.d.), http://www.transcanada.com/keystone.html.

[47] "Statement by the President on the Keystone XL Pipeline | The White House," (n.d.), http://www.whitehouse.gov/the-press-office/2012/01/18/statement-president-keystone-xl-pipeline.

Keystone Pipeline, Keystone Cushing Expansion Pipeline, and the proposed route of the Keystone-XL Pipeline are shown in Figure 4.

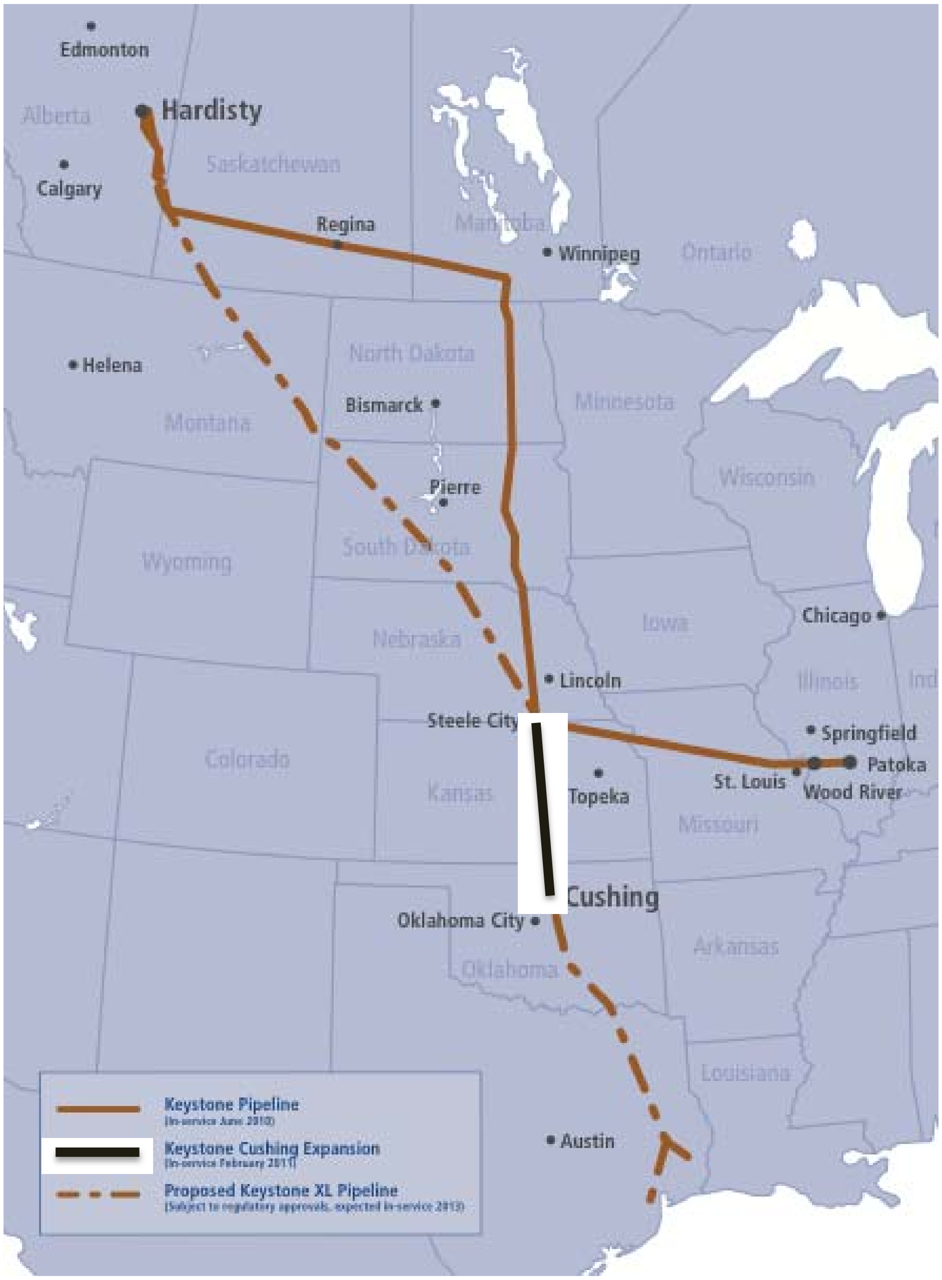


Figure 4. The proposed Keystone-XL Pipeline Route. The Keystone Cushing Expansion Extended the Keystone Pipeline System from Steele City, Kansas to the COTH. Adapted from TransCanada.[48]

[48] TransCanada, "Keystone Pipeline Project."

The COTH is one of the largest crude storage facilities in the world and the largest transportation facility on the continent. It is one of the world's major oil terminals, distributing more than 70% of the nation's crude oil on a daily basis.[49] The COTH has virtually no competition, and a significant disruption on the COTH would be catastrophic on a global scale.[50] The COTH is unprotected from attack and former CIA director James Woolsley described the facility as not hardened and an easy target.[51] In addition, the COTH has already been identified as a major pipeline hub and the hubs are the main source of vulnerability to the U.S. pipeline systems.[52]

The COTH is particularly vulnerable to a catastrophic interruption in service due to severe weather (e.g., Oklahoma's frequent ice storms, floods, and tornados) and/or a terrorist attack. A successful appropriately timed terrorist attack in the midst of a severe weather related event would result in widespread negative political, psychological, and economic impacts on the national level.[53] The large diameter pipelines coming into and leaving the COTH present the greatest vulnerability, as the large diameter pipes transport as much as 30–40 times more crude than smaller pipelines, but at the same time, reduce the number of required pipelines.[54] The hundreds of storage tanks at the COTH present the next largest vulnerability. An extreme event (weather event or terrorist attack) could significantly disrupt or destroy the COTH. It is a critical infrastructure vulnerable to attack and disruption that today receives less than adequate security consideration by industry and government.[55]

The COTH presents an optimal target for terrorists. In March 2011, the Houston Chronicle reported that the COTH stored 11% of the nation's inventory, which is double

[49] Wikipedia, the Free Encyclopedia, "Cushing, Oklahoma."

[50] Adams, *Terrorism & Oil*, 108; Anthony L. Kimery, "US Oil Complex Vulnerable to Attack," *Homeland Security Today*, November 27, 2007, http://www.hstoday.us/blogs/the-kimery-report/blog/us-oil-complex-vulnerable-to-attack/76d4b30a2b40c0a76d0fae629a06c50a.html.

[51] Kimery, "US Oil Complex Vulnerable to Attack.,"

[52] Lewis, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation*, 295.

[53] Adams, *Terrorism & Oil*, 107–108.

[54] Ibid., 107.

[55] Kimery, "US Oil Complex Vulnerable to Attack."

its capacity of only a few years ago and was expected to continue increasing storage capacity in the years to come. Enbridge, owner of a 1,000-acre tank farm at the COTH, maintains that the COTH's future as a major oil hub was promising and both Enbridge and other COTH owners were committed to the expansion of the COTH long into the future.[56]

A single large bomb the size of that used in the Oklahoma City bombing could destroy the COTH complex's ability to operate if placed appropriately. Multiple small bombs or insider sabotage could have similar effects. Additionally, an attack against the COTH storage tank farms could be catastrophic from an environmental and economic standpoint, as Cushing could no longer moderate the supply and demand and hence, pricing, for the U.S. oil industry. A tornado similar to the Moore, Oklahoma (1999) or the Joplin, Missouri (2011) tornadoes would be similarly catastrophic. A vulnerability assessment conducted by U.S. Department of Homeland Security Science, Technology, Engineering, and Math Scholars at Oklahoma State University found that the COTH was most vulnerable from an assault to the site, as well as oil storage tanks, pipelines, pumping stations, the control center, and utilities. The study found that a medium risk was associated with a small aircraft assault on the COTH, as the Cushing Municipal Airport is located immediately adjacent to the COTH. In addition, the study found multiple readily accessible entry methods.[57] See Figure 5.

[56] Clanton, "Oklahoma Oil Hub Helps Keep Oil Prices from Going Higher."

[57] Donald Furgeson, John Mahoney, and Brett Warfield, *Security Vulnerability Assessment of the Cushing Oil Storage Facility* (Stillwater, OK: Oklahoma State University, November 30, 2011).

ASSET/ATTACK SCENARIO ANALYSIS

Asset (Target)	Cutting Torch and/or Other Tools	Vehicles	On Foot	Insider	Small Arms	Heavy Arms	Rocket Propelled Grenade (RPG)	Mortars	Hand Grenades	Improvised Explosive Device (IED)	Suicide Bomber	Vehicle Borne IED (VBIED)	Small Aircraft	Large Aircraft	Score (Avg.)	Rank (Most Likely & Vulnerable)
	Entry Methods				Attack Methods											
People					Smaller Weapons					Explosives						
Management and Staff					2	2	2	2	2	3	1	3	5	2	2.4	9
Contractors					2	2	2	2	2	3	1	3	5	2	2.4	9
Visitors					2	2	2	2	2	3	1	3	2	2	2.1	10
Transportation Personnel					2	2	2	2	2	3	1	3	2	2	2.1	10
Delivery Personnel					1	1	1	1	1	1	1	1	1	1	1.0	13
Property																
Site	10	10	10	3	10	10	10	10	10	10	2	10	5	3	8.1	1
Tanks	10	10	10	3	2	2	10	10	10	10	2	9	5	3	6.9	2
Pipelines	10	10	10	3	2	2	9	9	9	10	2	9	5	3	6.6	3
Control Center	8	10	10	4	2	2	5	5	5	5	1	5	3	3	4.9	6
Pumping Station	8	10	10	4	2	2	9	9	9	10	1	8	3	3	6.3	4
Interchange Terminal	8	10	10	3	1	1	1	2	2	2	1	2	1	1	3.2	8
Utilities	8	10	10	4	2	2	2	2	2	10	1	3	1	1	4.1	7
Offices/ Buildings	3	3	3	3	2	2	2	2	2	2	1	1	1	1	2.0	11
Proprietary Information																
Operation Records	2	2	2	4	2	2	2	2	2	2	1	1	1	1	1.9	12
U.S. Pipeline Maps	6	6	6	6	5	5	5	5	5	2	2	2	8	9	5.1	5
Facility Plot Plans	2	2	2	4	2	2	2	2	2	2	1	1	1	1	1.9	12

Value Scale	
Linguistic	Numerical
Very High	10
High	9
High	8
Medium High	7
Medium	6
Medium	5
Medium Low	4
Low	3
Low	2
Very Low	1

Rank (Only for Rank Range)
Most Likely - Least Likely
Most Vulnerable- Least Vulnerable
1-12

Figure 5. Vulnerability Assessment Matrix of the COTH.[58]

[58] Furgeson, Mahoney, and Warfield, *Security Vulnerability Assessment of the Cushing Oil Storage Facility*.

A terrorist attack on the COTH would lack the traditional elements of mass causalities and iconic buildings; thus, some local and national authorities dismiss the COTH as a possible terrorist target.[59] However, the Department of Homeland Security Presidential Directive 7 states, "Terrorists seek to destroy, incapacitate, or exploit critical infrastructure and key resources across the United States to threaten national security, cause mass casualties, weaken our economy, and damage public morale and confidence."[60] Luft and Korin maintain that terrorist organizations have always been interested in targeting oil and gas facilities. In so doing, these groups are able to undermine the stability of the governments and weaken foreign powers with vested interests in their region. Luft and Korin further assert, that as security heightens around transportation networks, military bases and government installations, terrorists looking for a big bang might find oil interests. To quote al Qaeda, "the 'umbilical cord and lifeline of the crusader community,' the object of the next major assault on the west, an assault that could wreak havoc with America's economy and way of life." [61] Oil and gas pipelines have been a favored target of terrorists outside the United States, and the fact that terrorist groups have demonstrated the capability and intent to attack pipeline systems abroad raises the possibility that similar attacks could occur inside the homeland. Al Qaeda's online magazine, *Voice of Jihad*, declares that Al Qaeda "should strike petroleum interests in all areas which supply the United States."[62] This online magazine listed The Trans Alaskan Pipeline System as a target, but also included links to maps of oil facilities in Alaska, Texas, Louisiana, California, and Oklahoma.[63]

---

[59] Anthony L. Kimery, "Petrojihad USA: Policing the Pipelines," *Homeland Security Today*, September 2007, http://www.hstoday.us/index.php?id=483&cHash=081010&tx_ttnews%5Btt_news%5D=556.

[60] U.S. Department of Homeland Security, "Homeland Security Presidential Directive 7: Critical Infrastructure Identification, Prioritization, and Protection," *Homeland Security Presidential Directive 7*, December 17, 2003, http://www.dhs.gov/xabout/laws/gc_1214597989952.shtm.

[61] Gal Luft and Anne Korin, "Terror's Next Target," *Journal of International Security Affairs* (December 2003), http://www.iags.org/n0111041.htm.

[62] Kimery, "Petrojihad USA: Policing the Pipelines."

[63] Kimery, "US Oil Complex Vulnerable to Attack."

Attacks on oil and gas infrastructure have become the weapon of choice for international terrorists, irrespective of the political and social-financial conditions of the society under attack.[64] Over 10,000 terrorist attacks occurred during 2011, which affected approximately 45,000 victims in 70 countries and resulted in 12,500 deaths.[65] Data from terrorist attacks from 2007–2011 shows a sharp rise in the number of attacks directed at energy infrastructure, which includes fuel tankers, fuel pipelines, and electrical networks that increase from 299 attacks in 2010 to 438 attacks in 2011. During the same period, terrorist attacks on public places declined approximately 47%.[66] See Figures 6 and 7.

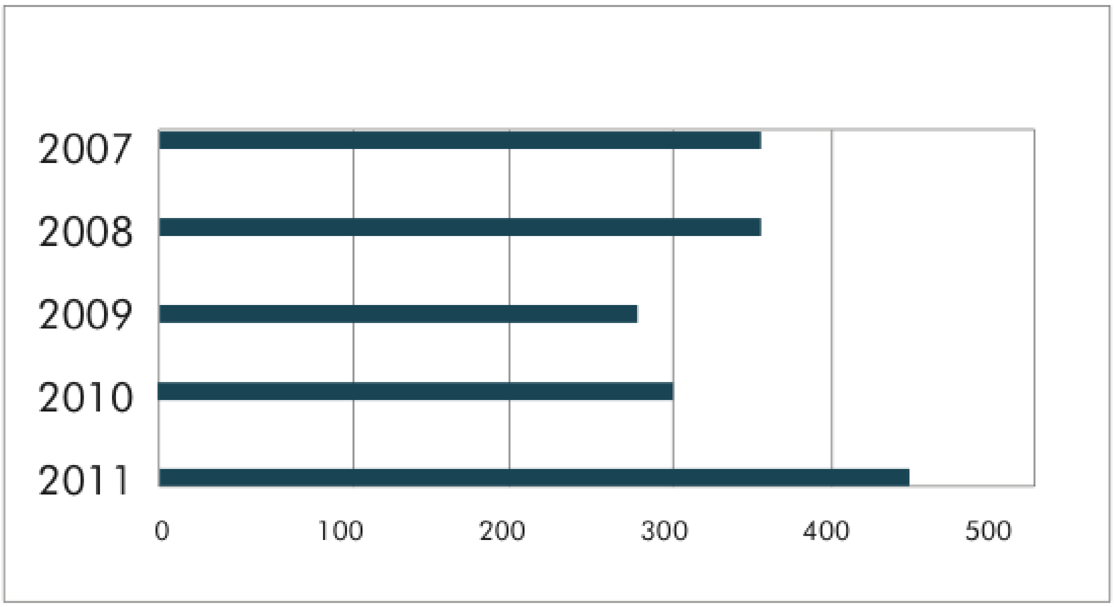


Figure 6. Terrorist Attacks on Energy Infrastructure.[67]

[64] Friedrich Steinhäusler et al., "Security Risks to the Oil and Gas Industry: Terrorist Capabilities," *Strategic Insights* 7, no. 1 (2008): 1–10.

[65] National Counterterrorism Center, *2011 Report on Terrorism* (Washington, DC: Director of National Intelligence, March 12, 2012).

[66] Ibid.

[67] Ibid.

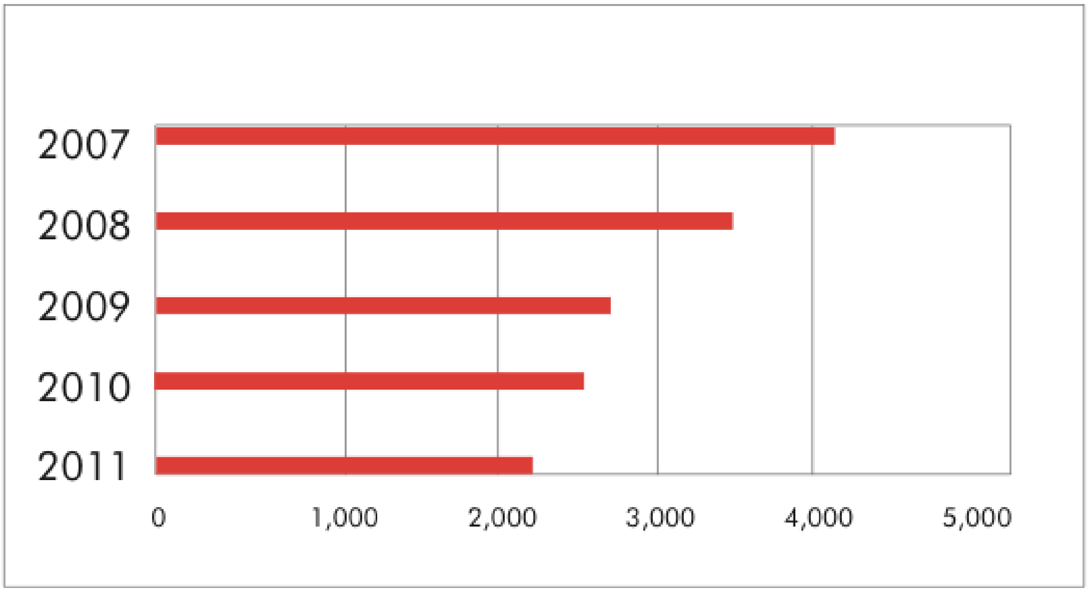


Figure 7. Terrorist Attacks on Public Places.[68]

Over two-thirds of terrorist attacks in 2011 were directed towards infrastructure or critical facilities. Transportation facilities and transportation infrastructure incurred damage in 27% of the 2011 attacks.[69] See Figure 8. Steinhäusler et al. provide multiple scenarios for coordinated attacks to the oil and gas industry and maintain that terrorists are likely to deploy coordinated attacks on oil infrastructure.[70] A major interruption of service at the COTH or other critical hubs would not only have a severe impact on the nation's oil reserves, but also pose a significant threat to an already suffering economy. At any given time, 10–11% percent of the nation's oil inventory resides in Cushing, and this percentage appears likely to rise. By the end of 2012, the added storage capacity at the COTH will increase from 46.3 billion barrels to 60.3 million barrels, a 23.7% expansion.[71] Seventy percent of the nation's crude oil flows through the COTH. With the

[68] National Counterterrorism Center, *2011 Report on Terrorism*.

[69] Ibid.

[70] Steinhäusler et al., "Security Risks to the Oil and Gas Industry: Terrorist Capabilities."

[71] Furgeson, Mahoney, and Warfield, *Security Vulnerability Assessment of the Cushing Oil Storage Facility*.

increase in storage capacity and the completion of the Keystone-XL pipeline, the percentage of the daily supply of crude oil flowing through the COTH is likely to increase.

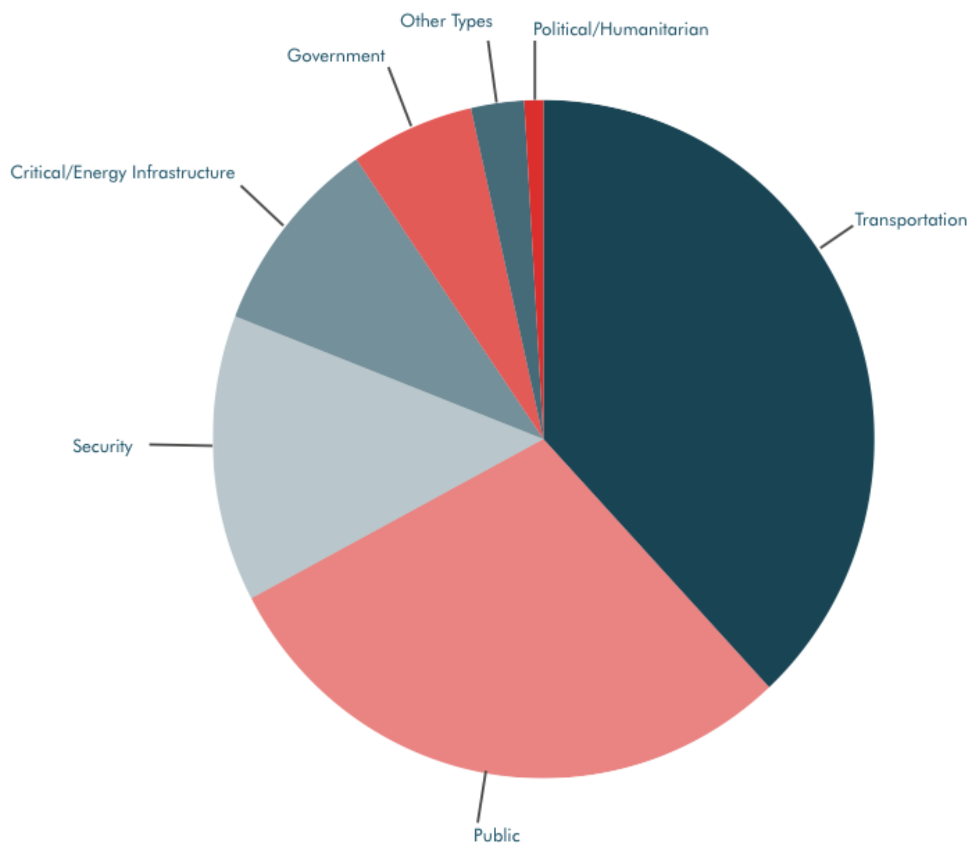


Figure 8. Terrorist Attacks Damaging Facilities by Facility Category.[72]

The decrees issued to Al Qaeda's followers to attack U.S. oil facilities were designed with the intent to disrupt the flow of oil available to America by bankrupting its economy by driving up world oil prices.[73] Any disruption to the flow of domestic oil might also increase U.S. reliance on foreign oil sources, which are also vulnerable to disruption for various reasons. According to the U.S. Energy Information Administration, "Both crude oil and petroleum product prices can be affected by events that have

[72] National Counterterrorism Center, *2011 Report on Terrorism*.

[73] Kimery, "US Oil Complex Vulnerable to Attack."

[merely] the potential to disrupt the flow of oil and products to market, including geopolitical and weather-related developments." Crude oil prices and key geopolitical and economic events are represented in Figure 9. Selected events, including natural disasters, affecting the price of crude from 2001–2011, are represented in Figure 10. Furthermore, the EIA indicated that events only need to create uncertainty in oil markets and that actual disruptions are not necessary.

Several major oil price shocks have occurred at the same time as supply disruptions triggered by political events, most notably the Arab Oil Embargo in 1973–74, the Iranian revolution and Iran-Iraq war in the late 1970s and early 1980s, and Iraq's invasion of Kuwait in 1990. More recently, disruptions to supply (or curbs on potential development of resources) from political events have been seen in Nigeria, Venezuela, Iraq, Iran, and Libya.[74]

[74] U.S. Energy Information Administration, "Energy & Financial Markets—U.S. Energy Information Administration (EIA)—U.S. Energy Information Administration (EIA)," *What Drives Crude Oil Prices?*, (n.d.), http://www.eia.gov/finance/markets/spot_prices.cfm.

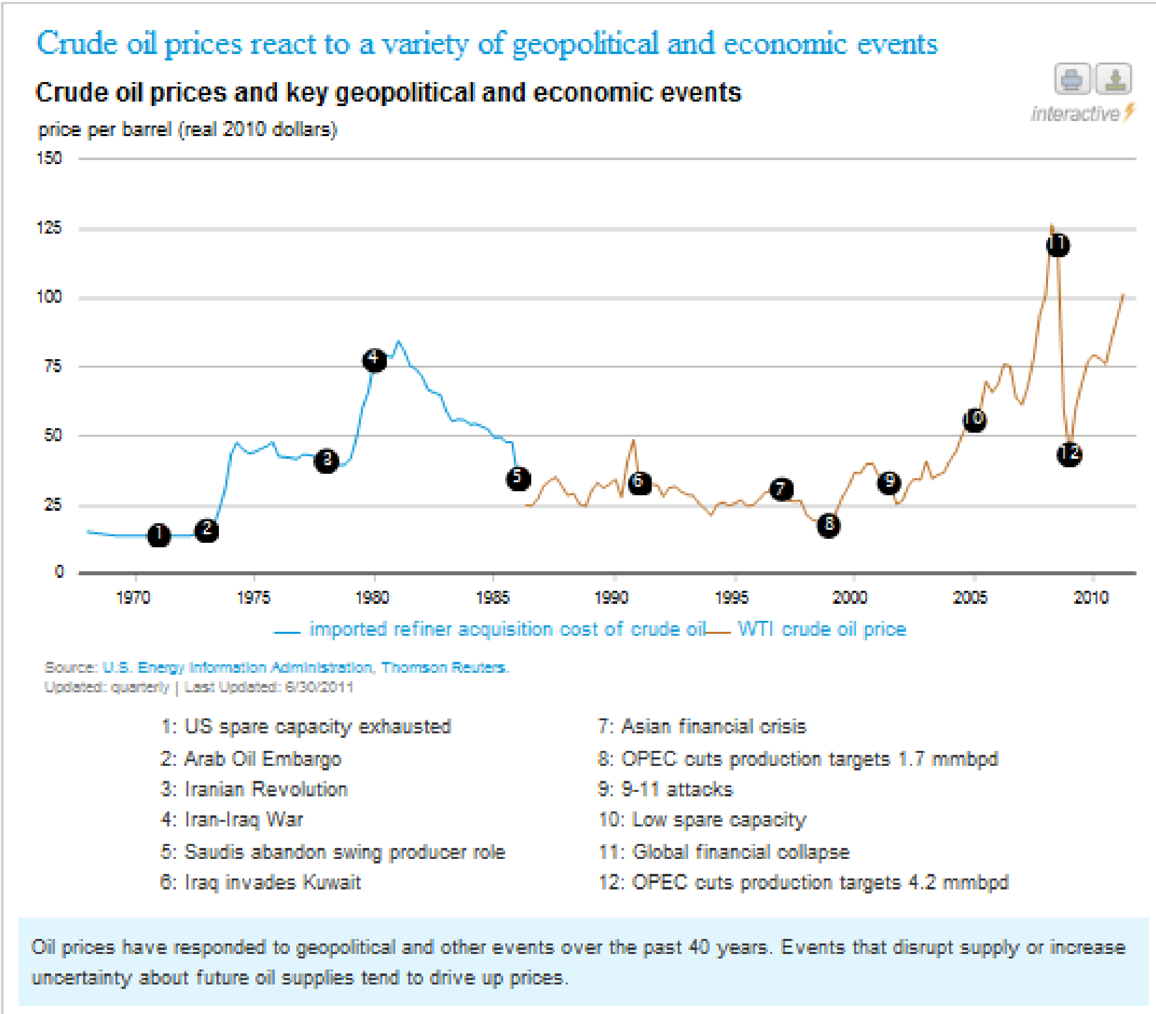


Figure 9. Geopolitical and Economic Influences on the Price of Crude Oil (1970–2010).[75]

[75] U.S. Energy Information Administration, “Energy & Financial Markets—U.S. Energy Information Administration (EIA)—U.S. Energy Information Administration (EIA).”

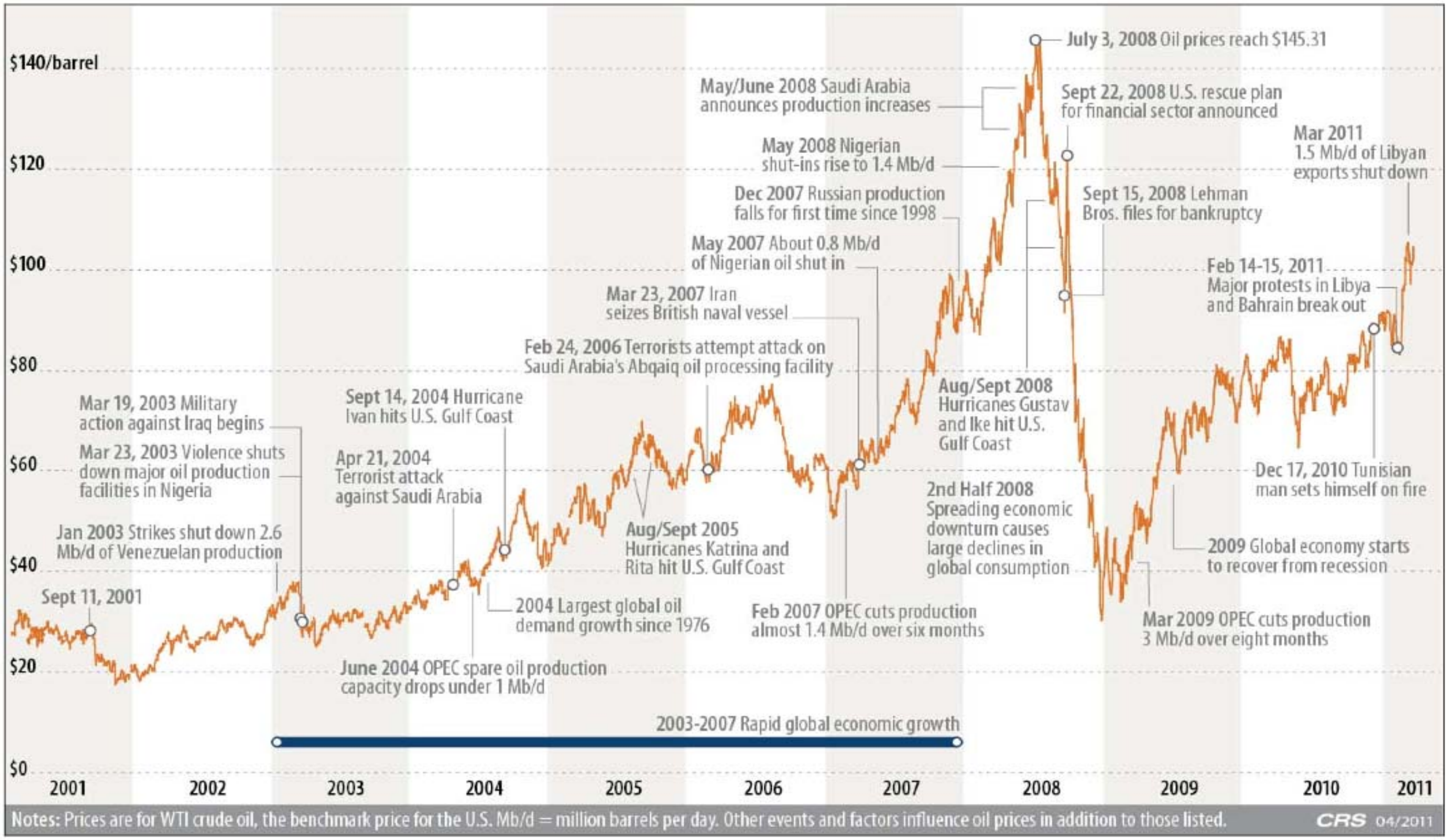


Figure 10. Selected Events Affecting the Price of Crude Oil in the United States (2001–2011)[76]

[76] U.S. Library of Congress, Congressional Research Service, *U.S. Oil Imports: Context and Considerations*, by Neelesh Nerurkar, CRS Report R41765 (Washington, DC: Office of Congressional Information and Publishing, April 1, 2011), http://www.fas.org/sgp/crs/misc/R41765.pdf.

In August 1979, the GAO warned, in a report to Congress, that pipelines are highly vulnerable to disruptions caused by human error, sabotage, or nature and that damage to facilities on just a few pipeline systems could greatly reduce domestic shipments, which would cause an energy shortage exceeding that of the 1973 Arab oil embargo when severe gas shortages created long lines at the gas pumps.[77] Luft and Korin conclude that despite the fact that only 28% of American oil was imported during the 1973 Arab oil embargo, the supply cuts effect on the American economy was profound. Oil prices quadrupled in only a matter of weeks. Today, with over half the U.S. crude oil supply being imported, the consequences and attack on a major oil installation or choke point in the crude oil infrastructure would be worse than the 1973 Arab oil embargo.[78] As an example of the strategic importance of oil distribution, former CIA Middle East field officer Robert Baer provides the following scenario, which presents an idea of the magnitude of a scenario in which oil supply is interrupted by a terrorist attack on oil hubs within the Kingdom of Saudi Arabia:

> A terrorist attack…on the Saudi oil complex or a simultaneous attack on a few of them is not a fictional scenario. A single terrorist cell hijacking an airplane in Kuwait or Bubai and crashing it into Abqaiq or Ras Tanura, could turn the complex into an inferno. This could take up to 50% of the Saudi oil off the market for at least 6 months and with it most of the world’s spare capacity, sending oil prices through the ceiling. Such an attack would be more economically damaging than a dirty nuclear bomb set off in midtown Manhattan or across from the White House in Lafayette square…[this] would be enough to bring the world’s oil-addicted economy to their knees, America’s along with them.[79]

For comparison purposes, a major disruption (weeks or months) of the COTH would remove approximately 70% of the U.S. crude supply from the market because it serves as the major distribution hub for U.S. crude to the Midwest and Gulf Coast states, which would be equally consequential as the scenario proposed by Baer. Former CIA director James Woolsey admitted that the COTH facility is a “soft target” that is not sufficiently

[77] Kimery, “US Oil Complex Vulnerable to Attack.”

[78] Ibid.

[79] Ibid.

hardened against an attack. In light of the strategic importance of the COTH, greater protection seems warranted. The oil stored in Cushing has a drastic impact on crude pricing. History has shown that when reserves at Cushing are low, prices increase greatly. Conversely, when stocks are high, prices plummet. Without a doubt, oil operations at Cushing have a global impact. In November 2007, an explosion damaged the Lakehead pipeline in northern Minnesota, which caused oil prices to spike an additional four dollars per barrel.[80] If the incident had disrupted flow of oil to Cushing, the effect on the market would have been more dramatic, possibly doubling the price. The major disruption of other critical hubs, such as the Houston Ship Channel, Longview, Texas; Vernon, Illinois; and Los Angeles hubs would have similar consequences. Kimery contends the oil market is so volatile that any bad news, even erroneous information, has a tremendous effect on pricing.[81]

> Critical infrastructure systems represent an enormous public investment where even minor disruptions can degrade the system's performance resulting in significant economic losses.[82] It is well within the realm of reality that a terrorist or other organization can identify critical hubs in the U.S. crude pipeline system by using information free available in the open source literature.[83] The Al Qaeda training manual states that by using open source information, it is possible to gather at least 80% of information about the enemy necessary to inflict terror.[84] Brown, et al. of the Naval Postgraduate School found that free, open source information often provides 100% of the information required to plan a devastating attack on an infrastructure system.[85]

The literature available regarding the vulnerability and hence, protection, of the U.S. crude pipeline infrastrcucture is lacking.

---

[80] Kimery, "US Oil Complex Vulnerable to Attack."

[81] Ibid.

[82] G. Brown et al., "Defending Critical Infrastructure," *Interfaces* 36, no. 6 (November 1, 2006): 530.

[83] Ibid., "Al Qaeda Training Manual," (n.d.), http://www.fas.org/irp/world/para/manualpart1.html.

[84] "Al Qaeda Training Manual."

[85] Brown et al., "Defending Critical Infrastructure," 530.

B. PROBLEM SPACE AND HYPOTHESES

Critical infrastructure systems represent an enormous public investment in which even minor disruptions can degrade the system's performance and result in significant economic losses.[86] It is well within the realm of reality that a terrorist or other organization can identify critical hubs in the U.S. crude pipeline infrastructure by using information free available in the open source literature.[87,88] Consequently, Lewis proposes that network analysis is one way to cope with size and complexity of a complex system.[89] A network analysis of the U.S. crude infrastructure pipeline system was conducted to identify critical components of the U.S. crude pipeline infrastructure. While a significant number of publications on single points of failure with regards to individual pipeline components do exist, network analysis of the crude infrastructure in the open literature does not.

The boundaries of this inquiry revolve around the U.S. crude pipeline infrastructure. Neither refined product or natural gas distribution pipelines were evaluated. Refined product and natural gas pipeline systems are separate from the crude oil pipeline infrastructure. The assumptions made are that the crude oil pipeline maps purchased from Rextag (http://www.rextagstrategies.com) correctly identify the pipeline locations that crisscross across the United States and that the proposed network analysis program accurately reflects the U.S. crude pipeline infrastructure represented in a network form.

2. Significance of Research

The significance of this inquiry is that critical hubs and critical links can be identified in the crude pipeline infrastructure, so that it is then possible to understand better how to protect the hubs from catastrophic loss due to natural or non-natural threats. Network analysis has been applied in other infrastructure sections to identify

[86] Brown et al., "Defending Critical Infrastructure," 530.

[87] Ibid.

[88] "Al Qaeda Training Manual."

[89] Lewis, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation*, 22.

vulnerabilities.[90] The U.S. economy and other critical infrastructure sectors are completely dependent on the timely and efficient delivery of crude oil to refineries. Crude oil is refined into a variety of other products, such as gasoline, diesel, heating oil, and jet fuel and then delivered to market. Should the delivery of a crude oil distribution system suffer a major disruption, the economy of the United States and the world would be significantly affected in a negative way. The hubs are the main source of vulnerability to the U.S. pipeline systems.[91] By identifying and protecting critical hubs in the crude pipeline infrastructure, it is possible to ensure delivery of crude oil and crude-based fuels, products, and lubricants to maintain the economic well being of the United States.

3. Hypotheses

The hypotheses are the following.

- The U.S. crude oil pipeline infrastructure is a complex network centered around one or more critical hubs.
- The U.S. crude oil pipeline infrastructure is subject to preferential attachment.
- The U.S. crude oil pipeline infrastructure is subject to cascade failure.

[90] Jian-Wei Wang and Li-Li Rong, “Cascade-based Attack Vulnerability on the US Power Grid,” *Safety Science* 47, no. 10 (December 2009): 1332–1336; P. Li et al., “A Limited Resource Model of Fault-tolerant Capability Against Cascading Failure of Complex Network,” *The European Physical Journal B* 62, no. 1 (March 19, 2008): 101–104; Eric Taquechel, “Layered Defense: Modeling Terrorist Transfer Threat Networks and Optimizing Network Risk Reduction,” *IEEE Network* (November/December 2010); Christos Nicolaides et al., “A Metric of Influential Spreading During Contagion Dynamics Through the Air Transportation Network,” *PLoSOne* 7, no. 7 (July 2012): 1–10.

[91] Lewis, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation*, 295.

THIS PAGE INTENTIONALLY LEFT BLANK

III. METHOD

The U.S. crude oil pipeline infrastructure was analyzed using the MBRA software tool developed by the Naval Postgraduate School Center for Homeland Defense and Security. This network analysis tool derives its results from the input of a network of nodes and its respective links by the software user.

The data for the analysis were gathered from crude pipeline maps published by Rextag. The crude pipeline maps identify transfer stations, pipelines, refinery locations, liquid storage terminals, and hubs in the U.S. crude pipeline infrastructure. These locations, pipelines, and refineries were entered into the MBRA software and the pipeline infrastructure represented as a network so that the network analysis could be conducted.

The output of the MBRA analysis assists the user in making objective decisions about the various variables inherent within the network in an effort to reduce risks and/or vulnerability within the network. The MBRA approach consists of two key components that assist the user in the analysis. These two components are network analysis and fault tree analysis, which do not necessarily have to be performed together. For the study of the crude oil pipeline infrastructure, the network analysis tool was utilized to determine which components of the network were most critical. The critical nodes identified by the analysis were ranked in order of their importance.

The MBRA software tool was chosen for this study due to its indifference in the system being analyzed. The MBRA method can be utilized on networks in which the link or nodes are tangible or intangible; thus, its applications range from the analysis of aqueduct systems to social networks. The universality of the software program and its systematic and methodical approach in the analysis of a network provided enough support to choose it as the tool to analyze the crude oil pipeline infrastructure to identify the critical nodes in the network. In the crude oil pipeline network, the nodes or areas of convergence or intersection are the most susceptible to damage or destruction, either by mechanical failure, natural events, or third-party intervention, which include damage by employees or terrorist activities. The MBRA software tool can then be used to analyze

the nodes' risk and vulnerability to identify the critical nodes within the network. The benefit of using the MBRA is to minimize risk in the crude oil pipeline network while determining the most efficient allocation of funds to the critical nodes identified in the network.[92]

The MBRA program estimates a power curve that can be utilized to determine the likelihood that a failure in the network will lead to a cascading failure and be utilized to assess system vulnerability. The MBRA program calculates a power law exponent, which identifies system resiliency against cascade failure.

Exceedence probability curves follow a power law and are commonly used in the insurance industry to assess risk. Power laws can be utilized to assess risk for nearly all hazards of interest to homeland security and safety engineering. The power law exponent dictates the steepness of the curve. Exponents greater than one indicate a resilient network. In other words, the higher the exponent, the lower the risk. Exponents less than one indicate a network at risk of a system-wide cascade failure. In this case, the lower the exponent, the higher the risk. Power law curves with exponents lower than 1.0 can be described as having a "fat tail" or "long tail." This fat tail indicates a higher probability of network vulnerability to cascade failure. This vulnerability indicates an increased risk for a Black Swan event. Black swan events are extreme and abnormal events responsible for large adaptations in nature, as well as human and system evolution.[93]

The terrorist attacks of 9/11 and the financial meltdown of 2008 are two examples of Black Swan events, which are considered as such because of their low probability, high consequence, and vast global ripple effect. The key to preventing Black Swans is to avoid too many links and large hubs to decrease connectivity. Connectivity increases the

[92] Taquechel, "Layered Defense: Modeling Terrorist Transfer Threat Networks and Optimizing Network Risk Reduction."

[93] Ted Lewis, *Bak's Sand Pile: Strategies for a Catastrophic World* (Williams, CA: AGILE Press, 2011), 35, 48, 65; Nassim Nicholas Taleb, *The Black Swan: The Impact of the Highly Improbable* (New York, NY: Random House, 2010); Ian Bremmer and Preston Keat, *The Fat Tail: The Power of Political Knowledge for Strategic Investing* (New York: Oxford University Press, 2009).

probability of a Black Swan event because of ripple effects due to dependence on connectedness, which allows a mechanism for seemingly insignificant events to magnify consequences.[94]

The x-axis on the power law curves in Figure 10 measure a percentage of the total consequence sum of the network, and the y-axis measures the percentage chance that a certain percentage of that sum will fail. For example, in Figure 11, a 9% chance exists that at least 8% of the “Entire Nation” network will fail as the result of a single initiating failure. For the PADD V network, note that an 18% chance exists that at least 8% of the network will fail as the result of a single initiating failure.[95]

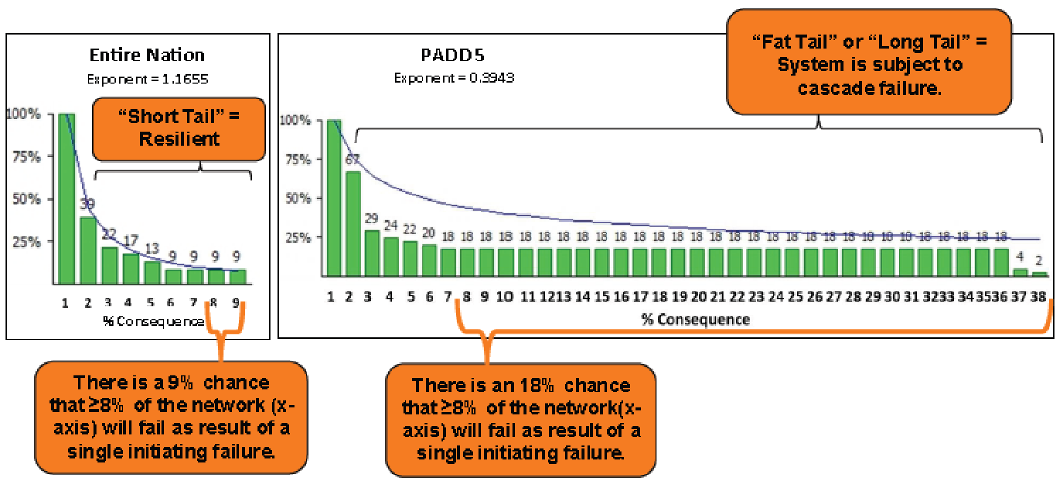


Figure 11. Representation of Power Law Curves and Exceedence Probability.

The analysis will determine if the crude oil infrastructure networks are susceptible to cascade failure and define critical hubs in the system. This information can be utilized to prepare recommendations to protect networks and critical hubs in the network model.

---

[94] Lewis, *Bak’s Sand Pile: Strategies for a Catastrophic World*, 35, 90.

[95] CHDS. “Model-Based Risk Analysis User Guide,” (n.d.), 20–21, http://www.chds.us/?media/resources&collection=53&type=SIMULATION.

A. SOURCES OF DATA

The data gathered for the analysis of the crude oil pipeline infrastructure were obtained through RexTag Strategies. Information contained within the maps regarding the crude oil pipelines utilized included the pipelines, oil refineries locations, liquid terminals, large oil fields, and oil seaports. The pipelines were input into the MBRA software directly while the other information listed above was used to determine the direction of oil flow through the network.

B. TRANSFER OF DATA INTO MBRA SOFTWARE

The pipelines were entered into the MBRA software, with the areas of convergence of multiple pipelines intersecting on the map denoted as nodes. Nodes were placed in areas where oil entered the system and where they exited the system, as in the case with the refineries denoted by red flags. Nodes were also identified in the system where pipelines crossed the U.S. border. The MBRA representation of the crude oil pipeline network is shown in Figure 12 and the representation of the links, nodes, and hubs are depicted in Figure 13. It should be noted that with the use of the MBRA software, the maps within the software were used purely for the individuals inputting the information into the program and had no effect on the analysis itself. Results derived from the MBRA analysis are determined by the relationship of the nodes and links and not the geospatial characteristics as observed on the map. In the case of this study, it was necessary to use the map to systematically put each pipeline in the MBRA software so as to compare it with the maps provided by RexTag Strategies and the National Geospatial-Intelligence Agency to ensure accuracy and avoid inadvertent omissions.

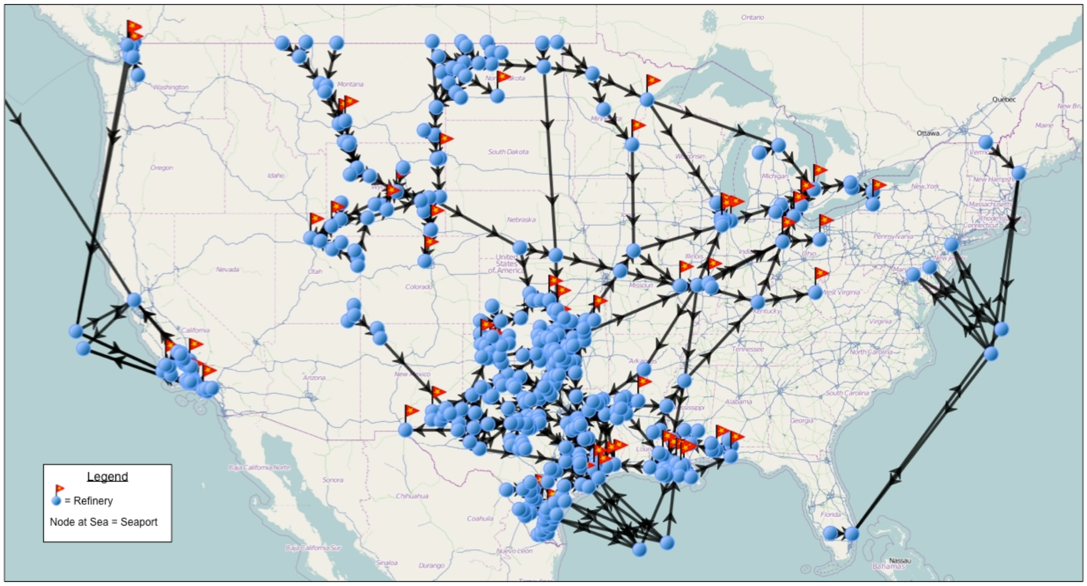


Figure 12. MBRA Representation of the Crude Oil Pipeline Network

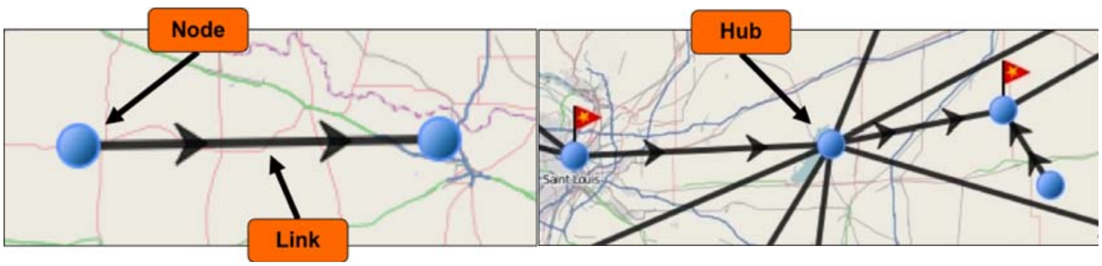


Figure 13. Nodes, Links, and Hubs, Arrows Indicate Direction of Flow

Assumptions of the investigators while inputting the data into the MBRA software included the direction of flow of the crude oil in the pipeline system and the application of virtual seaports. Rigorous investigation into pipeline maps did not lead to the determination of flow or pipe diameter. This minor setback was circumvented through the meticulous examination of each pipeline within the network and tracing each pipeline to its origin and final destination (refinery or seaport). The virtual seaports were entered into the MBRA software to represent the flow of oil via ship into and out of the network.

C. METHOD OF VALUE ASSIGNMENT

The MBRA software models the effects of security improvements at nodes, which in turn determines the overall network risk, but it does not provide initial threat, vulnerability, or consequence inputs.[96] These values, shown in Tables 1 and 2, were developed through analysis of past oil industry losses and were inputted in the MBRA software. A multiplier was applied to the original value assignment if the node or link were located or traveled through a high consequence area as identified in Figure 4. These values were objectively applied to each node and link within the entire network. The values for the threat and vulnerability of each node and link inputted into the system throughout the network are a percentage representing the probability of an attack occurring, and consequently, succeeding. The consequence applied to each node and link was the estimated costs of failure for each particular component in the system. Costs of component failure were estimated based on loss estimates of a single Gulf Coast refiner from both a 3-day and a 10-day interruption of service, in which direct (economic losses to the refiner) and indirect (losses due to reduced demand from suppliers and reduced sales by customers) were $97 million (3-day interruption) and $405 million (10-day interruption) per incident.[97] The maximum node value assignment was $20 billion, which was arrived at by using the $20 billion figure BP placed in escrow to repay those who had losses associated with the BP/Macondo/Deepwater Horizon incident.[98] Adjustments for environmental and human casualty considerations were accounted for by the multipliers depicted in Table 3.

Due to the increase of the consequence because of location on a waterway at the Houston Ship Cannel hub, the COTH was given equal consequence node value assignments as those, such as the Houston Ship Channel Hub to account for the critical

[96] CHDS. “Model-Based Risk Analysis User Guide,” 20–21.

[97] Scott Dynes, Eva Andrijcic, and M. Eric Johnson, “Costs to the U.S. Economy of Information Infrastructure Failures: Estimates from Field Studies and Economic Data,” *Proceedings of the Fifth Workshop on the Economics of Information Security, Cambridge University*, 2006, http://www.tuck.dartmouth.edu/cds-uploads/publications/pdf/Paper_WEIS_Costs.pdf.

[98] BP, “BP Establishes $20 Billion Claims Fund for Deepwater Horizon Spill and Outlines Dividend Decisions| Press Release | BP,” June 16, 2010, http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7062966.

nature of the COTH to the U.S. pipeline infrastructure. The threat parameter for the Houston Ship Channel hub was decreased to 50% because of the high activity level in the ship channel, law enforcement presence, and the significant presence of industrial facilities surrounding the Houston Ship Channel Hub. Threat and vulnerability assessments for the Houston Ship Channel and the COTH were conducted with input from federal, state, and local law enforcement representatives at the Naval Postgraduate School's Center for Homeland Defense and Security. An example of the relative threat level and vulnerability between the COTH and Houston Ship Channel is represented in Figure 14. Virtual seaports nodes were assigned threat level of 20% and a vulnerability level of 20 percent. All other threats and vulnerabilities levels were assigned as described in Tables 1–3.

Figure 14. Houston Ship Channel Oil Transfer and Storage Facility Hub (Left) Is Located in an Active Terminal Area Surrounded by Industrial Facilities and a Very Busy Waterway, While the COTH Is Isolated with in an Area with Low Activity and Easy Access to the Facility

Degree	**Threat**	**Vulnerability**	**Consequence $(millions)**
1	20%	100%	25
2	30%	100%	250
3	40%	100%	500
4	50%	100%	1,000
5 to 7	65%	100%	5,000
8 to 10	80%	100%	10,000
> 10	100%	100%	20,000

Table 1. Node Value Assignments

Criteria	**Threat**	**Vulnerability**	**Consequence $(millions)**
Within **1 state**	25%	25%	25
Crosses **2 states**	50%	50%	100
Crosses **3 states**	75%	75%	250
Crosses **4 states**	100%	100%	500

Table 2. Link Value Assignments

Consequence

Inland Waterway "OR" Coastal ⇨ 4X (original amount)

Increased population ⇨ 4X (original amount)

Table 3. Consequence Adjustment Factors

D. PARAMETERS OF THE ANALYSIS

The network was analyzed using the parameters of degrees and betweenness, with the objective function of identifying risk. Degrees represent the number of links connected to a specific node. The degrees of each node were used to calculate the overall impact each individual node had on the system. Betweenness accounts for the number of paths traveling through a specific node. This parameter is valuable in the analysis given that a node with a small degree could still have a significant impact of the flow through the network under certain circumstances. Finally, the objective function of risk was selected since this study centered on the identification of the critical nodes in the network. A separate simulation for the entire nation was conducted on the flow parameter.

1. Project Assumptions/Notes

1. Pipelines and oil basins in the Gulf of Mexico were excluded with the exception of seaports/pipelines/terminals where oil is brought into the U.S. pipeline system. Shipping routes crossing into the coastal United States are represented as a node on the coast linked to the pipeline system.
2. Pipelines crossing Mexico/Canada border are designated as nodes at the border linked to the pipeline system.
3. Links were assigned the same name as shown on map.
4. Assign nodes with the sequence name starting with a PADD number followed by the node’s numerical sequence; e.g., the first node in PADD V would be “5.1.”
5. A hub is defined as the areas of convergence at which multiple pipelines intersect on the map.
6. The MBRA network was based on the RexTag Map REX-WM-030 U.S. Crude Oil Pipelines.
7. Liquid storage terminals are not included in the MBRA network.
8. Virtual seaports are utilized to represent sea routes.

2. Hypothesis Testing

Each hypothesis was tested using the following methods.

- Hypothesis 1: The U.S. crude oil pipeline infrastructure is a complex network centered around one or more critical hubs.
    - Testing Method: MBRA Network Analysis, Identification of Critical Hubs
- Hypothesis 2: The U.S. crude oil pipeline infrastructure is subject to preferential attachment.
    - Testing Method: MBRA Network Analysis, Literature Review, Exceedence Probability
- Hypothesis 3: The U.S. crude oil pipeline infrastructure system is subject to cascade failure.
    - Testing Method: MBRA Network Analysis, Exceedence Probability

IV. RESULTS AND ANALYSES

The MBRA software tool used the degrees and betweenness of each node to determine the risk in the crude oil pipeline infrastructure network. The MBRA analysis identified the five most critical hubs in the crude oil pipeline network for the entire nation. These critical hubs, identified in descending order of criticality are as follows.

1. Cushing, Oklahoma (COTH)
2. Houston, Texas (Houston Ship Channel)
3. Vernon, Illinois
4. Texas City, Texas
5. Longview, Texas

Another output of the MBRA software was the exceedence probability of the network. Exceedence probability follows a power law, as recognized in complex systems and statistical physics.[99] It can be used to determine the likelihood a failure in the network will lead to a cascading failure, or the probability that an event of x size or larger will occur within a system and not simply a system component.[100] The process of analyzing the crude oil pipeline network was applied to each individual PADD to determine its respective critical nodes and identify the likelihood of a cascading failure. The parameters of the analysis remained the same, with the degrees and betweenness of each node in the PADD used to identify the risk within each respective network. The likelihood of a cascading failure increased across the country moving from PADD I to PADD V. The highest ranked critical node identified in each PADD were the following.

1. PADD I: the virtual seaport off the east coast representing ocean-shipping routes
2. PADD II: Cushing, Oklahoma (COTH)
3. PADD III: Houston, Texas

[99] Ian Dobson et al., "Complex Systems Analysis of Series of Blackouts: Cascading Failure, Critical Points, and Self-organization," *Chaos* 17, no. 2 (2007): 1–33.

[100] Ted Lewis, *Model-Based Risk Analysis of Complex Networks* (Center for Homeland Defense and Security, n.d.).

4. PADD IV: Platte County, Wyoming
5. PADD V: Los Angeles, California.

Table 4 details the results of the exceedence probability for the crude oil pipeline network in each PADD and the national network. Results indicate that PADDs II and IV are susceptible to cascade failure as both have an exceedence probability exponent less than 1. PADD I maintains the most resilient network, while the nation's network exceedence probability exponent is 1.1655.

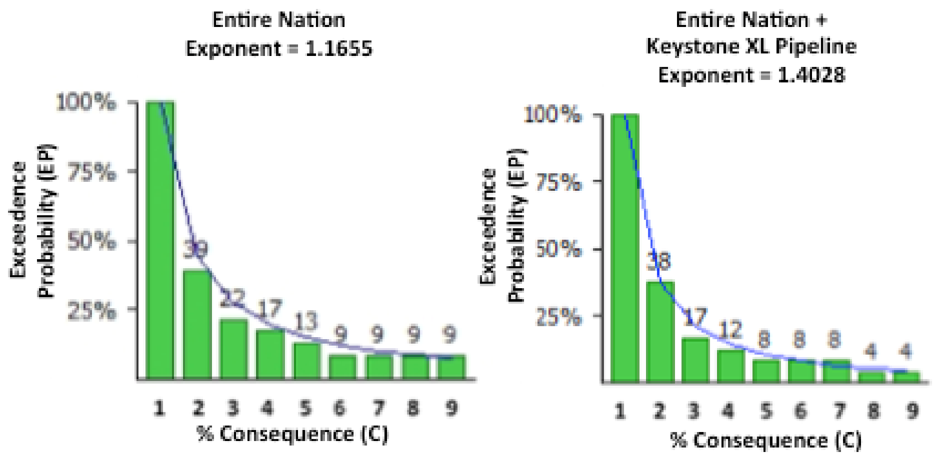
Exceedence Probability Exponent	
PADD	**Exponent**
1	1.4909
2	<0.8307
3	1.1485
4	1.0257
5	0.3943
Entire Nation Network	1.1655

Table 4. Exceedence Probability by PADD

A. KEYSTONE-XL PROPOSED ROUTE

The Keystone-XL proposed route through Steele City, Kansas down to the COTH via the Keystone Cushing Expansion, and again down to Nederland, Texas to serve the Port Arthur, Texas refinery complex was analyzed in the MBRA program. The proposed route of the Keystone-XL pipeline is depicted in Figure 4.

The addition of the proposed Keystone-XL route increased the exceedence probability exponent from the current value of 1.1655 for the entire nation to 1.4028, which indicates a 16.9% increase in network resiliency to cascade failure. See Figure 15.



Note the "fat tail" of the existing crude oil pipeline network suggesting "long tail" risk of a Black Swan event vs. the proposed network with the addition of the Keystone-XL pipeline with a tapering "short tail."

Figure 15. Exceedence Probability (y-axis) of the Existing National Crude Oil Pipeline Network with and without the Keystone-XL Pipeline Proposed Route Represented in the Network Analysis

Probable Maximum Loss Risk (PMLRisk) was calculated by applying exceedence probability to risk assessment science. PMLRisk is the expected loss due to a hazard of size x or larger and is a worst-case estimate of consequence, rather than an average-case estimate, which is commonly used to assess risk. Lewis defines PMLRisk as:[101]

PMLRisk = Exceedence Probability x Consequence.

The application of PMLRisk to the existing U.S. crude oil pipeline infrastructure with the proposed addition of the Keystone-XL pipeline to the national network resulted in a PMLRisk profile as described in Figure 16. The addition of the Keystone-XL

[101] Lewis, *Model-Based Risk Analysis of Complex Networks.*

pipeline to the existing crude oil pipeline infrastructure reduces PMLRisk by 55% (PMLRisk is highest at the highest consequence). The percent decrease in risk was calculated by the following formula:

Percent Decrease = (PMLRisk Existing Network—PMLRisk Addition of Keystone-XL)/(PMLRisk Existing Network).

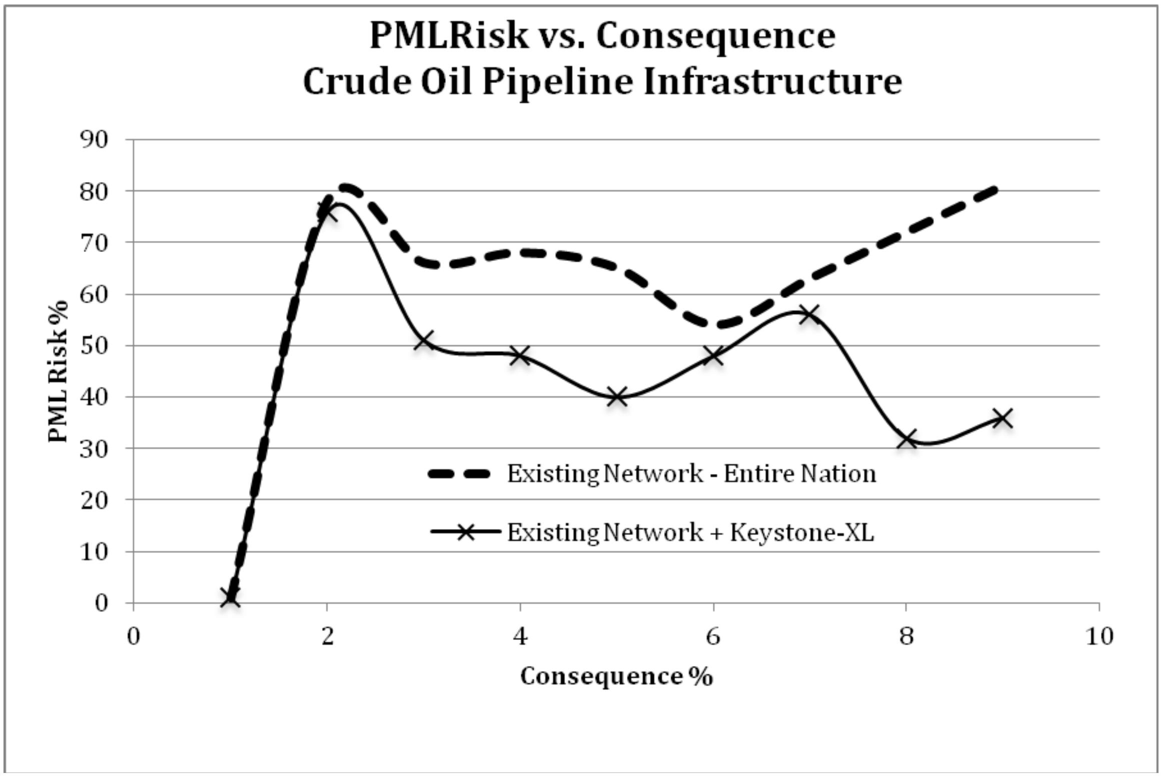


Figure 16. PMLRisk vs. Consequence for the Existing Crude Oil Pipeline Network and with the Addition of the Keystone-XL Pipeline to the Network

B. KEYSTONE-XL ALTERNATIVE ROUTES

Alternatives were considered to determine if re-routing the Keystone-XL could increase the resiliency of the nation’s crude network against cascade failure. Five alternative routes were evaluated against the network with the Keystone-XL proposed path. Results indicate that the proposed Keytsone-XL path had the highest exponent and presented the most resilient option. See Figure 13. Route options are limited to the West by the Rocky Mountain Range and to the East by distance, the Great Lakes, Mississippi

River, and a lack of refining capacity. U.S. refining capacity is highly concentrated along the Gulf Coast between Galveston, Texas and Baton, Rouge, Louisiana.[102] Table 5 lists the exceedence probability exponent of each alternative.

The alternative routes evaluated were the following.

1. Keystone-XL directly to Houston
2. Keystone-XL through Childress, Texas and Cushing and down to Houston
3. Keystone-XL through Childress and to both Cushing and Houston (from Childress)
4. Keystone-XL through Cushing and down to Houston (avoids Keystone Cushing Expansion at Steele City, Kansas)
5. Keystone-XL through Wood River, IL and down to Houston

Exceedence Probability Exponent	
Alternative	**Exponent**
Actual Proposed Path	1.40
1	1.12
2	1.06
3	1.38
4	1.12
5	1.16

Table 5. Exceedence Probability Exponent by Alternative.

[102] Lewis, *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation*, 297–298.

Regardless of alternative route, each simulation sequence identified the COTH as the most critical hub in the network. See Figure 17. Figure 17 represents the critical hubs identified for each alternative route for the proposed Keystone-XL pipeline. In each instance, the COTH remained the most critical hub in the national crude oil pipeline network.

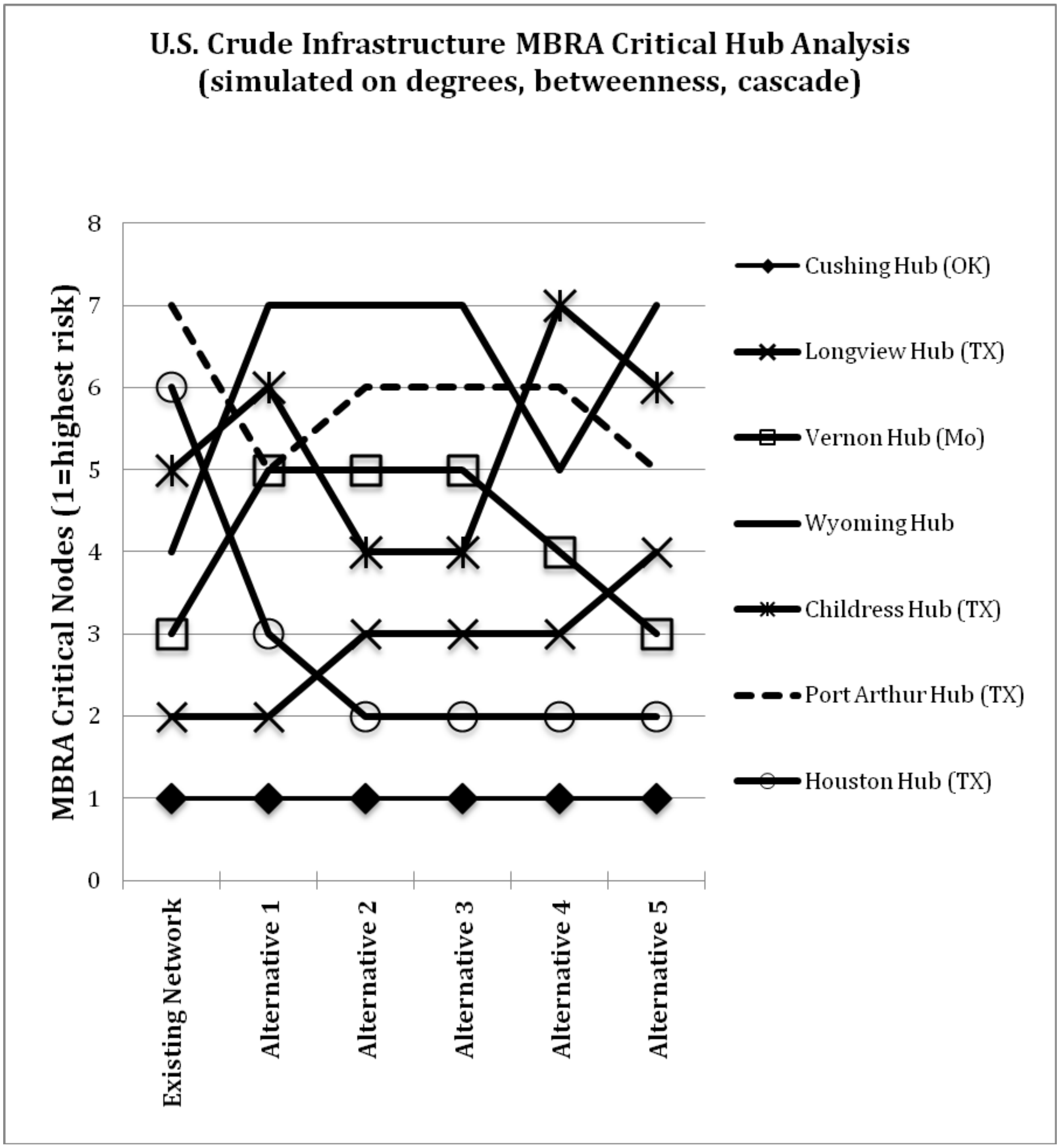


Figure 17. Critical Hub Analysis of Existing Network vs. Alternatives Routes for the Proposed Keystone-XL Pipeline

C. CRITICAL HUBS IN INDIVIDUAL PADDS

MBRA simulations of the crude oil infrastructure networks within each individual PADD were conducted to determine the critical components of the crude oil infrastructure network for each PADD. The critical components for each PADD are as follows.

1. PADD I

1. Ocean-shipping routes
2. Boca Raton, Florida
3. Portland, Maine
4. Shipping route from Newport, Vermont, where crude enters the country from Canada to the hub at Portland, Maine
5. Buffalo, New York

2. PADD II

1. Cushing, Oklahoma
2. Vernon, Illinois
3. Chicago, Illinois
4. Toledo, Ohio
5. Cleveland, Ohio

3. PADD III

1. Houston, Texas
2. Texas City, Texas
3. Singleton, Texas
4. Ballinger, Texas
5. Coleman, Texas

The critical hubs for PADD III are concentrated in Texas, with the Gulf Coast region of Texas being critical to the successful operation of PADD III. See Figure 18.

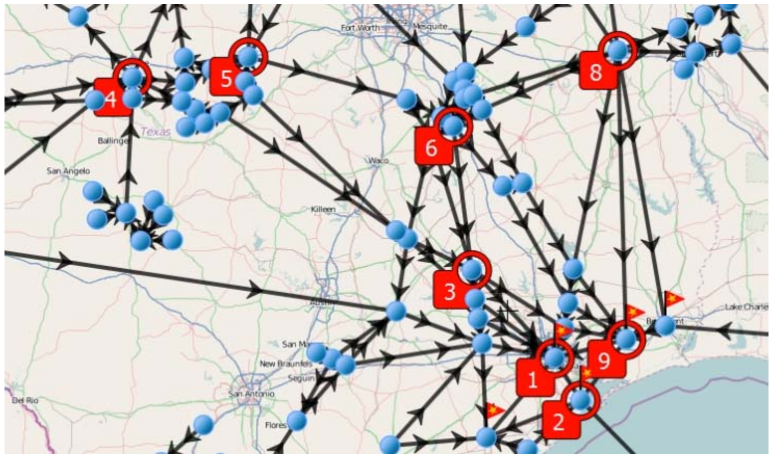


Figure 18. PADD III Critical Hubs Are All Located in Texas

4. PADD IV

Due to the lack of geographic landmarks that would aid in naming particular hubs in the Wyoming area, the critical hubs in PADD IV are represented pictorially in Figure 19.

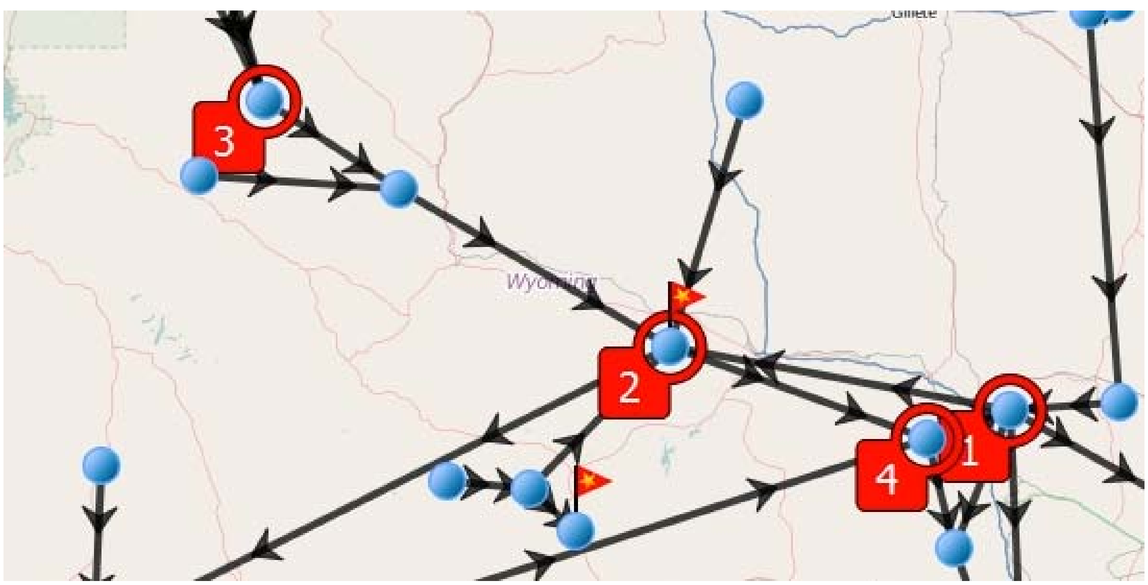


Figure 19. Pictoral Representation of Critical Hubs in PADD IV in the State of Wyoming.

5. PADD V

1. Long Beach, CA (Los Angeles)
2. Ocean shipping routes Canada and Alaska
3. Crockett, California
4. La Palma, California
5. Thousand Oaks, California

D. FLOW SIMULATION

The MBRA was run for the entire nation and simulated against the MBRA parameter for flow. The results showed an equal exceedence probability exponent to the original simulation, which considered betweenness, degrees, and risk. This may have occurred because actual flow rates were not available and could not be calculated or estimated from the pipeline maps since pipeline diameter and parallel configurations were not provided. Thus, the flow simulation may not be a valid estimation of the risk associated with flow rate in the national crude oil pipeline system.

1. Hypothesis Testing Results

- Hypothesis 1: The U.S. crude oil pipeline infrastructure is a complex network centered around one or more critical hubs.
    - Result: The MBRA network analysis identified critical hubs for the entire national network, as well as regional networks within each PADD.
    - Decision: Accept Hypothesis 1.
- Hypothesis 2: The U.S. crude oil pipeline infrastructure is subject to preferential attachment.
    - Result: The MBRA network analysis identified critical hubs for the entire national network whereby new pipelines could be attached. Five alternatives routes for the Keystone-XL pipeline were evaluated. The proposed route to the COTH and down to Houston provided the most resilient network in the analysis.
    - Decision: Accept Hypothesis 2.

- Hypothesis 3: The U.S. crude pipeline infrastructure system is subject to cascade failure:
  - Result: The MBRA network analysis identified PADDs II and IV as being subject to cascade failure. Critical hubs for the entire national network, as well as regional networks within each PADD, were identified whereby disruption of the critical hubs could cause cascade effects.
  - Decision: Accept Hypothesis 3.

THIS PAGE INTENTIONALLY LEFT BLANK

V. DISCUSSION

Pipelines often span long distances traveling through remote and sometimes vulnerable areas. For this reason, they are considered soft targets. Protecting all 55,000 miles of the U.S. crude oil pipeline would be a daunting, costly, and ultimately, unachievable task. However, protecting the U.S. crude oil pipeline network as a whole is a very achievable goal. This analysis was performed with the purpose of identifying the most critical parts of the U.S. crude oil pipeline network. Pipeline operators have said for many years that what constitutes a critical asset has not been well defined and is open to interpretation, which makes securing them a challenge.[103] By having a clear understanding of where the most critical parts of the network are located, it is then possible to better protect the entire network. The results of this analysis should be used as a starting point to increase the effectiveness of resources used to secure the crude oil pipeline network.

In parts of the Middle East, interruptions of the crude oil pipeline network are commonplace as a result of terrorist attacks. It does not require much in the form of manpower or resources to successfully attack a pipeline, refinery, or oil tanker.[104] Fortunately, the United States does not experience these types of interruptions on a regular basis. While terrorism is always a threat to the network, failures such as the BP Texas City refinery explosion and the Deepwater Horizon/BP incident can be equally as damaging but much more preventable.[105] Safety and security are intertwined, and each should be considered when taking steps to increase the robustness of the crude oil pipeline network. Currently, the largest threat to the pipelines in the network is corrosion,

---

[103] U.S. Library of Congress, Congressional Research Service, *Pipeline Safety and Security: Federal Programs*, by Paul W. Parfomak, CRS Report RL33347 (Washington, DC: Office of Congressional Information and Publishing, Updated February 29, 2008).

[104] Steinhäusler et al., “Security Risks to the Oil and Gas Industry: Terrorist Capabilities.”

[105] Michael D. Larrañaga et al., *Incident Analysis: Macondo Prospect 252-1 Deepwater Horizon Well Control Incident* (Boots & Coots Center for Fire Safety & Pressure Control: Oklahoma State University, 2011); Michael D. Larrañaga et al., *Incident Analysis: H1-ST1 Development Well: Montara Wellhead Platform Release* (Boots & Coots Center for Fire Safety & Pressure Control: Oklahoma State University, 2011).

which is difficult to detect and can lead to large leaks that result in ecological damage, monetary loss, and possibly, loss of life from ensuing explosions.[106] Maintaining the structural integrity of the networks pipelines and refineries is equally as important as securing the network from possible terrorist attacks. A culture of safety and security is crucial to network integrity.

The results from the nationwide network analysis indicate that the network as a whole is fairly robust and well designed from crude delivery standpoint. The analysis identified several areas of increased risk of cascade failure, which could cause a large interruption in the network and interrupt delivery to certain portions of the country as a result of a terrorist attack, natural disaster, or other catastrophic event. The analysis calculated the exceedence probability of the network and the network within each individual PADD. It is recommended that the five most critical nodes in the national crude oil pipeline infrastructure be assessed more thoroughly to ensure they are not vulnerable. The network should also be assessed to identify how design changes could lessen the criticality on these nodes and spread the risk more throughout the network. A more robust network would help lessen the impact of a high consequence event causing a cascading failure (Black Swan).

The results indicate that PADD II and PADD V are susceptible to cascade failure, with PADD V being the most vulnerable. Due to the geography of the region, PADD V is independent from the rest of the country. The isolation of PADD V combined with the realistic scenario of a cascading event due to a terrorist attack or other catastrophic incident, is cause for concern and should be evaluated further. The COTH is located in PADD II. Considering the critical nature of the COTH and other hubs, it is recommended that some physical barrier, such as a National Guard facility or military base, be constructed around the COTH to prevent a terrorist attack and provide resources for a large-scale response to the COTH. This type of physical barrier would limit access to the COTH, an increased law enforcement presence associated with facilities of this type, an increased fire department response capability, and simply, an increase in the number of

[106] Parker, "The Pipeline Industry Meets Grief Unimaginable: Congress Reacts with the Pipeline Safety Improvement Act of 2002."

security-vetted personnel able to observe facility boundaries. Undoubtedly, local citizens, environmental groups, many politicians, and others would view this disruptive suggestion negatively. However, the catastrophic loss of the COTH and other critical hubs within the crude oil pipeline network would lead to long-standing and negative, political, economic, and social implications that likely outweigh negative factors associated with leaving the hubs vulnerable. Regardless of whether this recommendation is accepted or not, hardening with regards to security of the COTH and critical hubs in each PADD, should be completed to protect against catastrophic interruption of service from terrorist attack.

This hardening of critical hubs should include components of the concept of Integrated Physical Protection (IPT) consisting of the following.[107]

1. State-of-the-art technical, and operational countermeasures to enable management to reduce the probability of success of a terror attack.
2. Increased emphasis on a corporate security culture, and thereby, strengthen corporate resilience to consequences of a terror attack and minimize the insider threat.
3. Continuous security training at all levels to reduce the probability for the occurrence of a terror attack and to reduce downtime after a terror attack.
4. Regular threat and risk assessment activities to identify, qualify, and quantify risks and countermeasures in a changing and complex environment.
5. Evaluation and update of strategies and countermeasures based on risk analyses by considering the cost benefit factor.
6. Strengthen cooperation between private owners of the facilities, related government security agencies, law enforcement, and first responders.

The addition of the proposed Keystone-XL pipeline increases the resiliency of the crude oil pipeline infrastructure against cascade failure and significantly reduces the PMLRisk associated with a Black Swan event. Hence, the potential for a catastrophic loss of U.S. capacity to distribute oil to refineries throughout the United States is greatly reduced by the addition of the Keystone-XL pipeline to the network. The Obama Administration should reconsider its controversial denial of a permit to complete the Keystone-XL pipeline that will carry oil from Alberta, Canada to the COTH.

[107] Steinhäusler et al., “Security Risks to the Oil and Gas Industry: Terrorist Capabilities.”

A. STRENGTHS/WEAKNESSES OF MBRA

A major advantage of using the MBRA method is that it directs attention to the most critical areas in a network subsequently to aid in minimizing those areas at greatest risk from disruption. Consequently, a potential disadvantage is that this process could overlook smaller links and nodes in the system. With a majority of the focus being on the critical nodes following the analysis, the smaller components in the system could be left vulnerable to degradation or attack with the potential of cascading effects within the system.

Another disadvantage in the analysis of the network is that the MBRA program does not allow for the representation of the multiple lines, in this case, pipelines running in parallel, originating and terminating at identical nodes. This insufficiency has the potential to influence the output of the analysis adversely given that one of the parameters of the model analysis is degrees (or number of pipelines that connect to individual nodes). This parameter of the analysis calculates the number of links entering and leaving each node in the network to determine its significance within the system. Another weakness of the program is its lack of identification of the source and sink nodes in the network that would be useful to the analysis due to the higher significance these components play in the actual system.

Regardless of the weaknesses, the MBRA network modeling and analysis tool provides valuable insight into the risks associated with attack vulnerability and cascade failure of a network system. The MBRA tool provides a mechanism to compute probable maximum loss risk. Network modeling is perhaps the simplest method of representing and analyzing systems of all sizes, regardless of their complexity while embracing system components and relationships among components. In addition, the MBRA calculates exceedence probabilities of cascade failure within a system. This calculation is ideal because network failures are systemic and cascade failures commonly occur in complex systems, such as power grids, nuclear power plants, telecommunication systems, and Internet exploits.[108] As such, the results of this study suggest that emphasis should be

[108] Lewis, *Model-Based Risk Analysis of Complex Networks*.

placed on critical hubs to protect the entire network from cascade failure. It is not suggested that any other component of the nation's crude pipeline infrastructure be ignored from either a security or safety standpoint.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. CONCLUSION

Much of the crude oil pipeline infrastructure is vulnerable to catastrophic failure and has served beyond its intended design life. Protecting all 55,000 miles of the U.S. crude oil pipeline infrastructure from catastrophic failure is an unachievable goal. Protection of the network can be achieved by protecting hubs from catastrophic failure, allocating resources to critical hubs, and by employing the concepts of integrated physical protection. In addition to protecting the five most critical hubs in the entire U.S. crude oil pipeline network, critical hubs in each PADD should be protected.

The resiliency of the crude oil pipeline infrastructure is vital to sustain the U.S. economy, military, and standard of living. The analysis has identified key areas within the network that require additional attention to ensure their integrity. A key concept to alleviate the risk across a network is to incorporate redundancy through the design of additional hubs positioned strategically across the network. The completion of the Keystone-XL pipeline from Canada through the COTH and down to Nederland, Texas will improve the resiliency of the network and reduce the risk associated with a Black Swan event. Further analysis should be conducted to explore alternative and additional pipelines to accomplish this effort. Also, by increasing safety across the network by the individual pipeline operators, security of the infrastructure will be enhanced. By focusing resources on the identified critical areas, the network as a whole will become more resilient to disruption by a terrorist attack, natural disaster, or other catastrophic events. The results of this analysis should be used as a starting point to increase network resiliency and prioritize the use of resources to secure the crude oil pipeline network against cascade failure and a Black Swan event.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Adams, Neal. *Terrorism & Oil*. Tulsa, OK PennWell Corp., 2003.

"Al Qaeda Training Manual." (n.d.). http://www.fas.org/irp/world/para/manualpart1.html.

Boyd, Dan. "Milestones in the Oklahoma Oil and Gas Industry." *Oklahoma Geological Survey*. (n.d.). http://www.ogs.ou.edu/oilgasmilestones.php.

BP. "BP Establishes $20 Billion Claims Fund for Deepwater Horizon Spill and Outlines Dividend Decisions| Press Release | BP." June 16, 2010. http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7062966.

———. "BP Pipelines—Our History." (n.d.). http://www.bppipelines.com/history.html.

Bremmer, Ian, and Preston Keat. *The Fat Tail: The Power of Political Knowledge for Strategic Investing*. New York: Oxford University Press, 2009.

Brown, G., M. Carlyle, J. Salmeron, and K. Wood. "Defending Critical Infrastructure." *Interfaces* 36, no. 6 (November 1, 2006): 530.

Christos Nicolaides, Luis Cueto-Felgueroso, Mata C. Gonzalez, and Ruben Juanes. "A Metric of Influential Spreading During Contagion Dynamics Through the Air Transportation Network." *PLoSOne* 7, no. 7 (July 2012): 1–10.

"CIA–The World Factbook." (n.d.). https://www.cia.gov/library/publications/the-world-factbook/rankorder/2174rank.html.

Clanton, Brett. "Oklahoma Oil Hub Helps Keep Oil Prices from Going Higher." *Houston Chronicle*. March 3, 2011. http://www.chron.com/business/energy/article/Oklahoma-oil-hub-helps-keep-oil-prices-from-going-1550679.php.

Department of Homeland Security. "DHS Critical Infrastructure." (n.d.). http://www.dhs.gov/files/programs/gc_1189168948944.shtm.

DHS. "DHS-Energy Sector: Critical Infrastructure." (n.d.). http://www.dhs.gov/files/programs/gc_1189013411585.shtm.

Dobson, Ian, Benjamin A. Carreras, Vickie E. Lynch, and David E. Newman. "Complex Systems Analysis of Series of Blackouts: Cascading Failure, Critical Points, and Self-organization." *Chaos* 17, no. 2 (2007): 1–33.

DOT-PHMSA. “PHMSA—Organization—Office of Pipeline Safety.” (n.d.). http://www.phmsa.dot.gov/portal/site/PHMSA/menuitem.ebdc7a8a7e39f2e55cf2031050248a0c/?vgnextoid=ca9fe4fca0380110VgnVCM100000762c7798RCRD&vgnextchannel=8938143389d8c010VgnVCM1000008049a8c0RCRD&vgnextfmt=print.

Dynes, Scott, Eva Andrijcic, and M. Eric Johnson. “Costs to the U.S. Economy of Information Infrastructure Failures: Estimates from Field Studies and Economic Data.” *Proceedings of the Fifth Workshop on the Economics of Information Security, Cambridge University*, 2006. http://www.tuck.dartmouth.edu/cds-uploads/publications/pdf/Paper_WEIS_Costs.pdf.

Furgeson, Donald, John Mahoney, and Brett Warfield. *Security Vulnerability Assessment of the Cushing Oil Storage Facility*. Stillwater, OK: Oklahoma State University, November 30, 2011.

Hartman, Floyd L. “1879: Tidewater Pipe Company—World’s 1st Successful Oil Pipeline.” 2009. www.smethporthistory.org/coryville/tidewatermap.html.

Hopkins, Phil. “Oil and Gas Pipelines: Yesterday and Today.” 2007. www.penspen.com/Downloads/Papers/.../OilandGasPipelines.pdf.

Institute for Energy Research. “The Booming Sooners: Vast Energy, Low Prices, Low Unemployment.” July 11, 2012. http://www.instituteforenergyresearch.org/2012/07/11/those-booming-sooners-plentiful-energy-low-energy-prices-low-unemployment/.

Kimery, Anthony L. “Petrojihad USA: Policing the Pipelines.” *Homeland Security Today*. September 2007. http://www.hstoday.us/index.php?id=483&cHash=081010&tx_ttnews%5Btt_news%5D=556.

———. “US Oil Complex Vulnerable to Attack.” *Homeland Security Today*. November 27, 2007. http://www.hstoday.us/blogs/the-kimery-report/blog/us-oil-complex-vulnerable-to-attack/76d4b30a2b40c0a76d0fae629a06c50a.html.

Larrañaga, Michael D. and Angela Sandoval. “Current Safety Issues Associated with Natural Gas Transportation and Distribution.” Presented at the X Congresso y Exposición Iberoamericana de Tecnologías en Prevención de Incendio, Protección Ambiental y Seguridad Industrial SEGUR-Fire 2001, Caracas, Venezuela, July 2001.

Larrañaga, Michael D., Patrick Smith, Heley Kincannon, and Qingsheng Wang. *Incident Analysis: H1-ST1 Development Well: Montara Wellhead Platform Release*. Boots & Coots Center for Fire Safety & Pressure Control: Oklahoma State University, 2011.

———. *Incident Analysis: Macondo Prospect 252-1 Deepwater Horizon Well Control Incident*. Boots & Coots Center for Fire Safety & Pressure Control: Oklahoma State University, 2011.

Lewis, Ted. *Bak's Sand Pile: Strategies for a Catastrophic World*. Williams, CA: AGILE Press, 2011.

———. *Model-Based Risk Analysis of Complex Networks*. Center for Homeland Defense and Security, n.d.

Lewis, Theodore. *Critical Infrastructure Protection in Homeland Security: Defending a Networked Nation*. Hoboken, NJ: John Wiley & Sons, 2006.

Li, P., B.-H. Wang, H. Sun, P. Gao, and T. Zhou. "A Limited Resource Model of Fault-tolerant Capability Against Cascading Failure of Complex Network." *The European Physical Journal B* 62, no. 1 (March 19, 2008): 101–104.

Luft, Gal, and Anne Korin. "Terror's Next Target." *Journal of International Security Affairs* (December 2003). http://www.iags.org/n0111041.htm.

Minerva, Ida. *The History of the Standard Oil Company: 2 Volumes in 1*. The MacMillan Company, 1904.

National Archives. "Records of the Petroleum Administration for Defense." 1950.

National Counterterrorism Center. *2011 Report on Terrorism*. Washington, DC: Director of National Intelligence, March 12, 2012.

Oil Infrastructure Subgroup. "Crude Oil Infrastructure." *NPC North American Resource Development Study*. September 15, 2011. http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCYQFjAA&url=http%3A%2F%2Fwww.npc.org%2FPrudent_Development-Topic_Papers%2F1-7_Crude_Oil_Infrastructure_Paper.pdf&ei=q2wxT8enGZTHsQLl7IjwBg&usg=AFQjCNEj8mFdkY0ysInCPfGzfpveDVEWzg.

Parker, Carol. "The Pipeline Industry Meets Grief Unimaginable: Congress Reacts with the Pipeline Safety Improvement Act of 2002." *Natural Resources Journal* 44, no. 1 (2004): 244–282.

Pees, Samuel T. "Oil History." 2004. http://www.petroleumhistory.org/OilHistory/pages/Pipelines/BigYear.html.

Phillips, Matthew. "Unlocking the Crude Oil Bottleneck at Cushing." *Business Week.* May 16, 2012. http://www.businessweek.com/articles/2012-05-16/unlocking-the-crude-oil-bottleneck-at-cushing#p1.

"Statement by the President on the Keystone XL Pipeline | The White House." (n.d.). http://www.whitehouse.gov/the-press-office/2012/01/18/statement-president-keystone-xl-pipeline.

Steinhäusler, Friedrich, P. Furthner, W. Heidegger, S. Rydell, and L. Zaitseva. "Security Risks to the Oil and Gas Industry: Terrorist Capabilities." *Strategic Insights* 7, no. 1 (2008): 1–10.

Taleb, Nassim Nicholas. *The Black Swan: The Impact of the Highly Improbable*. New York, NY: Random House, 2010.

Taquechel, Eric. "Layered Defense: Modeling Terrorist Transfer Threat Networks and Optimizing Network Risk Reduction." *IEEE Network* (November/December 2010).

TransCanada. "Keystone Pipeline Project." (n.d.). http://www.transcanada.com/keystone.html.

Trench, Cheryl J. "How Pipelines Make the Oil Market Work—Their Networks, Operation and Regulation." December 2001. http://www.pipeline101.com/Overview/crude-pl.html.

U.S. Department of Homeland Security. "Homeland Security Presidential Directive 7: Critical Infrastructure Identification, Prioritization, and Protection." *Homeland Security Presidential Directive 7*, December 17, 2003. http://www.dhs.gov/xabout/laws/gc_1214597989952.shtm.

U.S. Energy Information Administration. "Energy & Financial Markets—U.S. Energy Information Administration (EIA)—U.S. Energy Information Administration (EIA)." *What Drives Crude Oil Prices?*, (n.d.). http://www.eia.gov/finance/markets/spot_prices.cfm.

U.S. Library of Congress. Congressional Research Service. *America's Pipelines Safe and Secure: Key Issues for Congress*, by Paul W. Parfomak. CRS Report R4153. Washington, DC: Office of Congressional Information and Publishing, March 13, 2012.

———. *Pipeline Safety and Security: Federal Programs*, by Paul W. Parfomak. CRS Report RL33347. Washington, DC: Office of Congressional Information and Publishing, Updated February 29, 2008.

———. *U.S. Oil Imports: Context and Considerations*, by Neelesh Nerurkar. CRS Report R41765. Washington, DC: Office of Congressional Information and Publishing, April 1, 2011. http://www.fas.org/sgp/crs/misc/R41765.pdf.

Wang, Jian-Wei and Li-Li Rong. "Cascade-based Attack Vulnerability on the US Power Grid." *Safety Science* 47, no. 10 (December 2009): 1332–1336.

Wikipedia, the Free Encyclopedia. “Cushing, Oklahoma.” (n.d.). http://en.wikipedia.org/wiki/Cushing,_Oklahoma.

———. “Tulsa, Oklahoma.” (n.d.). http://en.wikipedia.org/wiki/Tulsa,_Oklahoma.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Honorable John Howard, MD, JD, MPH, LLM
   Director, NIOSH - Centers for Disease Control and Prevention
   U.S. Department of Health and Human Services
   Washington, DC

4. Honorable Tim Manning
   Deputy Administrator
   DHS - Federal Emergency Management Agency
   Washington, DC

5. Honorable Rafael Moure-Eraso, CIH
   Chairman, Chemical Safety Board
   Washington, DC

6. Honorable John Bresland
   Board Member, Chemical Safety Board
   Washington, DC

7. Honorable Kim Edd Carter
   Director, Office of Homeland Security
   Oklahoma City, Oklahoma

8. Honorable Stephen P. McKeever
   Secretary of Science and Technology
   State of Oklahoma
   Stillwater, Oklahoma

9. Honorable Tonya Hoover
   State Fire Marshal - CALFIRE
   State of California
   Sacramento, California